Chapter 7
Agro-management Practices for Sustainable Coconut Production

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Abstract Improved agro-techniques have been standardized, through research conducted over several decades, to achieve sustainable productivity and profitability in coconut farming. Adoption of refined nursery techniques enables production of quality planting material. Poly bag nursery technique with bio-priming of biofertilizer formulations helps in production of superior quality seedlings. The good management practices validated to improve the productivity in adult coconut palms include integrated nutrient management, green manuring/cover cropping, soil and water conservation measures, weed management, irrigation, fertigation and cropping/farming system approach. Fertigation helps to increase the fertilizer use efficiency, saves fertilizer costs, reduces labour requirement and ensures continuous nutrient supply in tune with crop requirement. Sustainable cropping system models are evolved to optimize utilization of natural resources and to enhance the economic viability. Integrated farming involving cultivation of fodder grass in the interspaces of coconut and integration of animal husbandry enterprises offer significant ecological and economic benefits. Effective formulations of agriculturally important microorganisms such as nitrogen fixers, plant growth-promoting rhizobacteria and arbuscular mycorrhizal fungi have been developed as valuable inputs for sustainable crop production. Lignocellulosic residues from coconut plantations can be con-

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verted into brown, granular vermicastings using earthworms. Organic farming practices with focus on building soil biological fertility foundations through integrated application of organic and bio-inputs including recycling of waste biomass, in situ cultivation and incorporation of leguminous cover crops and biofertilizers of *Azospirillum* and *Bacillus* and other cultural practices are combined with micro-irrigation techniques to obviate moisture stress and enable sustainable coconut production, in an environment-friendly way.

7.1 Introduction

The coconut palm, a native of humid tropics, is grown extensively in coastal areas between the latitudes 26°N and 26°S of the equator. The main coconut-growing areas are located in Asia, Oceania, West Indies, Central and South America and West and East Africa, and the major production comes from the Asia-Pacific region. Though the palm grows up to 1000 m above mean sea level, most of the commercial coconut cultivation is up to an altitude of 600 m (Ohler 1999). Conditions near the sea are ideal for vigorous growth and fruiting of the palm, but it comes up well even hundreds of kilometres in the inland away from the sea. The coconut palm is also planted widely on banks between fields of other crops. As the palm has perennial growth habit with a prolonged reproductive phase of 44 months (from the initiation of the inflorescence primordium to full maturity of the nuts), the weather conditions at different stages of the development cycle influence the growth and production of nuts.

Temperature is an important weather factor that has great influence on the growth and productivity of the palm. The palm prefers less diurnal variation between day and night temperatures and does not tolerate extremes of temperature. The aberrations in weather such as long spells of hot and dry weather, severe winters and extremes of temperatures are not favourable for coconut growing. The ideal temperature requirement for vigorous growth and yield of the palm is in the range of 27–32 °C with a diurnal variation of not more than 7 °C. Abnormalities in fruit development and reduction in yield of palms occur when temperature drops to less than 15 °C (Child 1974). High temperature during the flowering stage leads to drying up of the developing inflorescences and results in a decrease in production. The palm requires plenty of sunlight, and shaded condition does not favour proper development of the palm. Sunshine in excess of 2000 h in a year, with 120 h of sunshine per month, is ideal for the better growth of the palm (Menon and Pandalai 1960; Nair 1979). Maintenance of proper level of moisture in coconut basin either through well-distributed rainfall or irrigation and provision of sufficient drainage in waterlogged areas is essential for proper growth of the palm. The palm comes up well in areas receiving well-distributed rainfall ranging from 1000 mm to 3000 mm annually. Persley (1992) reported that coconut requires an annual rainfall of at least 1800 mm, evenly distributed throughout the year for optimum production. Ideal relative humidity (RH) for best growth and production is 80–90% (Child 1974). RH below 60% results in stomata closure that restricts transpiration, while RH higher than 90% predisposes the palm to a number of diseases.

The highly adaptable nature of the palm makes it an ideal crop to be cultivated under diverse soil conditions ranging from littoral sands to clayey soils, ill-drained low-lying areas to well-drained hill slopes and strongly acidic peaty soils to alkaline calcareous soils (Khan et al. 1979). In the littoral (coastal) sand which has many unfavourable features for successful cultivation of many other crops, the coconut palm can be cultivated provided special care is taken from the early stages of growth with organic manuring and watering. In the west coast of India, the major soil types where coconut is grown extensively are laterites, littoral sands and red sandy loams, while deltaic alluvium, red soils and littoral sand are the major soils along the east coast of the country. The soil type for the best growth of the palm is found to be deltaic alluvial followed by red sandy loam. A well-drained soil with a 1.0–1.5 m depth, rich in organic matter and having good fertility and water-holding capacity, is well suited. Though the palm tolerates salinity up to a pH of 8.5, a pH range of 5.0–7.5 supports better growth of the palm (John 1952; Nair 1979; Khan et al. 1979).

Coconut farming at the global level is constrained by the low productivity which is mainly due to lack of proper management, senility, applications of low level of inputs and poor health of soil. In order to make the farming profitable in the scenario of worsening climatic conditions and severe constraints on the available natural resource base, it is necessary to adopt scientific management practices to attain higher yield per unit area of land, time and inputs. The technological advancements made so far are of great relevance to achieve sustainable productivity and to enhance economic viability of coconut farming.

7.2 Quality Planting Material Production

Being the foundation for successful coconut production, the quality of planting material largely determines the ultimate returns from coconut. As it is a perennial crop, the yield performance of the crop will be known only after several years of planting and any mistake in the selection of seedlings leads to considerable economic loss to the farmer for several decades. In the absence of a viable technology for vegetative method of propagation, coconut is propagated only through seeds. The seedling selection is very important as the palm does not breed true to itself due to the cross-breeding nature. The fact that certain seedling characters are strongly correlated with earliness in flowering, nut yield and copra production makes the seedling selection highly relevant for sustainable coconut farming (Ramadasan et al. 1993). It is possible to produce quality seedlings through a series of selections at different stages. Nursery techniques to produce quality seedlings have been standardized, which involves several steps, viz. selection of seed gardens, selection of mother palms, collection of seed nuts, storage of seed nuts, site selection and raising of nursery with proper care and management, as well as selection of seedlings. Please refer to Chap. 4 on Varietal Improvement for details.

7.2.1 Collection of Seed Nuts

Suitable time for seed nut collection will vary from country to country and region to region within the country according to seasonal factors. Maturity and development of nuts for satisfactory germination and the period of storage required (which depends on the preparedness for sowing in the nursery) are to be considered. Generally seed nuts are harvested during February to May in the west coast of India so that the rains of south-west monsoon can be taken advantage of to sow the nuts (Menon and Pandalai 1960).

Nuts harvested during April to July and sown during June to September germinated earlier, the average time being 125 days after sowing. However, there is no harm in collecting seed nuts in other months, if there is a peak coconut yield. But nuts harvested from August to December and sown during October to February required a longer time (about 190 days) for germination. However, the total germination percentage was almost the same for nuts harvested in all months, indicating that the nuts germinate satisfactorily irrespective of the month of harvest, if proper nursery techniques are adopted (Nelliat et al. 1976). In the case of East Coast Tall variety, nuts collected from February to August and stored for 1 or 2 months gave high percentage of germination (Sundaresan et al. 1974).

Though Nelliat et al. (1976) reported that there is no difference in performance between palms raised from nuts which are 11 to 14 months old, the generally accepted practice is to sow 11–12-month-old nuts. While conducting studies on hybrid seed collection in Côte d'Ivoire, Wuidart and Nuce de Lamothe (1981a) suggested to collect the bunches when one or two nuts just begin to turn brown. Nuts under 11 months germinated slowly than 11–12-month-old nuts and gave a large number of abnormal sprouts. From India, Chattopadhyay and Hore (2012) observed early and maximum germination and better seedling vigour when seed nuts with higher weight (1100 g) was used when compared to seed nut with 600 g weight. Wickramaratne et al. (1987) from Sri Lanka warned that seed nuts should not be selected or rejected on the basis of size, quantity of nut water or shape, as they are not strongly correlated with germination. Only immature, empty, exceptionally small or outsized nuts should be rejected, and all others could be used as seed nuts.

7.2.2 Storage of Seed Nuts

Though the seed nut season starts in February in the west coast of India, the nuts may have to be stored for about 4 months because the nuts can be sown in the nursery only with the start of south-west monsoon in June. During this hot period of storage, care has to be taken to avoid drying of nuts (Menon and Pandalai 1960).

According to Fremond et al. (1966), storage of seed nuts in the shade for 1 month is essential for breaking the dormancy. Kailash Rao and Srirama Rao (1968) advocated storage of seed nuts for 2 months for the West Coast Tall variety of coconut.

Marimuthu and Natarajan (2005) also found that to get more quality seedlings, the seed nuts are to be stored for 1 month in open shade followed by sand curing for 2–3 months. The storage time should be shorter in the case of seed nuts of dwarf varieties of coconut.

Nampoothiri et al. (1973) studied the variation in germination pattern of five coconut cultivars and one hybrid by harvesting 12-month-old seed nuts at monthly intervals from February to June and sowing in June (to give storage periods of 4 months, 3 months, 2 months, 1 month and no storage, respectively). They found that when the number of days taken for germination from the date of harvest was considered, storage does not appear to be necessary. Prolonged storage of cultivars such as Laccadive Ordinary and Gangabondam adversely affected germination. Nuts of Straight Settlement Apricot was found to germinate 50–80 days after harvest, and sprouts emerge if stored for longer than about 2 months.

7.2.3 Pre-sowing Treatment

Among the many pre-sowing treatments recommended for reducing the period of germination, soaking of seed nuts in water for a period up to 15 days has been found to result in quicker and better germination, but in case the period is prolonged, germination and quality of seedlings will be adversely affected. In an experiment in Tanzania, water soaking recorded the lowest period for germination (81.1 days) as against 142.9 days for untreated seed nuts (Thomas 1974). Germination process was hastened by soaking the nuts in water or in a solution of 0.01 M potassium nitrate and 0.02 M sodium carbonate for 48 h (Thomas 1974), chopping the husk from both ends of the nuts as well as injecting different hormones (Liyanage 1952; Deshpande and Kulkarni 1962) and major and minor nutrients (Menon and Pandalai 1960; Sumathykutty Amma 1964).

A practice that can be followed to improve sprouting is the slicing off of a part of the husk ridge at the stalk end of the nut above the germination eye. Removal of the exocarp facilitates penetration of water through the husk, and the moisture will reach the sprout earlier, providing optimum moisture conditions in the husk for germination and sprouting. Sometimes a slice of husk is also removed on the opposite side of the nut, permitting easier penetration of the roots through the husk into the soil (Fremond et al. 1966; Borah 1991; Ugbah and Akpan 2003). Peries (1984) compared a pre-nursery system (slicing seed nuts and transplanting sprouted seed nuts from pre-nursery beds to nursery beds, soon after sprouting) with the conventional nursery. Though the rate of sprouting at the end of 20 weeks in the pre-nursery system was higher (76%) as compared to 67% in the conventional nursery, the number of quality seedlings produced was more or less the same. The cost of production of seedlings in the pre-nursery system was more than over 50% of the conventional nursery. Though slicing the seed nut facilitated sprouting, transplanting sprouted seed nuts from the pre-nursery caused a setback to the development of the seedlings.

7.2.4 Nursery Raising Techniques

Coconut seed is not to be sown directly into the field. The nursery practices are intended to provide optimum conditions for the germination of seed nuts and subsequent growth of seedlings so as to get high percentage of quality seedlings from the nuts sown in the nursery. It also makes watering as well as pest and disease control easier and more efficient. Selection of good quality seedlings for field planting is possible only by raising them in a nursery.

Site Selection and Raising Nursery For raising the nursery, the site selected should be well-drained, with coarse-textured soil and near dependable water source for irrigation. Raising nursery in open condition is the best; however, it can be raised anywhere if there is not too much shade as in the coconut garden itself. The seedlings become lean and lanky and have an unhealthy appearance under heavy shade. The layout of the nursery is to be designed according to the irrigation system used. Beds, which are long and narrow, are to be prepared with provision for walking space or drains in between, as found necessary.

To facilitate access to the seedlings, these are sometimes planted in double rows, keeping the spacing at about 15 cm within the row and about 45 cm between rows. In general, spacing of about 60 cm is kept between the beds in the nursery. When the seed nuts are sown too close, the emerging seedlings will become etiolated and lanky. Muliyar and Pillai (1989) suggested keeping a distance of 80 cm between beds. This will help irrigating the nursery and examination of seedlings from the sides without getting inside the beds.

Sowing of Seed Nuts The positioning of the soft eye is important, as it is believed that this affects sprouting (germination). In the Philippines, trimming the edge (below which the functional eye through which the sprout emerges) and positioning the nut with the flat surface downward and ridge pointing upward were found to facilitate sprouting and normal development of seedlings (Anon 1975).

Laying the nuts with the soft eye towards the upper side helps the sprout to emerge faster, as it would be closer to the surface. Placing the nuts with the soft eye closer to the lower surface may ensure that the soft eye, and therefore the embryo, remains in contact with the nut water for a longer period, which might enhance germination. Since there is no method to determine the position of the soft eye of the seed nut, it is not possible to position it in the nursery such that early sprouting is facilitated. Practically, the best planting position of the nuts is horizontal, irrespective of which side is lowermost. This will increase the speed of sprouting and reduce nursery costs considerably (Wickramaratne and Padmasiri 1986). As the roots grow rather quickly, the position of the soft eye in relation to contact with the soil will be of only minor importance, provided the nuts are adequately watered. Romney et al. (1968) opined that seedlings from horizontally placed nuts are less likely to be damaged at transplanting because the attachment between shoot and nuts is much better protected by the husk. In Papua New Guinea, the rate of germination and subsequent growth of seedlings were much faster in horizontal sowing than vertical sowing. In 8 weeks from transplanting, 47% germination was recorded for the former method against 39% in the latter (Kenman 1973). Remison and Mgbeze (1988) and Chattopadhyay et al. (2004) also reported beneficial effect of horizontal sowing in comparison with vertical sowing.

In some countries, nuts are planted in a vertical position, permitting the roots to grow through the husk for a longer time, which is an advantage at transplanting. But this can be done only with nuts that have enough water to fill almost the entire cavity, such that the haustorium does not lose its contact with the nut water. This method of sowing will be ideal when the seedlings are to be transported to distant places.

Results of a large-scale trial conducted by Wuidart and Nuce de Lamothe (1981b) showed that MYD germinates very rapidly and WAT slowly. MYD, RLT and WAT took 51, 81 and 126 days, respectively, to attain 50% germination. It was concluded that late germination was influenced by husk moisture, water content of nuts and the distance separating the haustorium from this water. The differences between varieties are, thus, determined mainly by the time the haustorium takes to reach the water in the nut's cavity.

Borah (1991) observed that seed nuts that floated vertically upright in water were more vigorous than those floating horizontally. The strong and stout seedlings from such nuts resulted from early germination and less exposure to drought. The coconut water may be absorbed completely within a period of about 5 months, and by this time about half the kernel may still be left in the nut, available to the developing seedling.

The seed nuts can be sown in flat beds if the soil is well-drained. Otherwise, they should be sown in raised beds at a spacing of 40 cm between rows and 30 cm between the nuts during May–June, either horizontally or vertically in 20–25 cm deep trenches. Spacing of seed nuts in the nursery is determined based on the duration for which the seedlings are to be retained in the nursery. In Odisha and Godavari areas of India, where much older seedlings are preferred for planting, it is usual to transplant the seedlings when they are 1 year old to a secondary nursery with a spacing of 90–150 cm between seedlings. In Sri Lanka, in the conventional nursery, seed nuts are laid in the nursery beds spaced at 45 cm between rows and 15 cm within row and remain there for 7 to 9 months until seedlings are selected for field planting (Anon 1971). The depth of sowing is to be adjusted such that the husk appears just above the surface of soil.

7.2.5 Care and Management of Nursery

The seedlings are to be properly maintained with adequate watering, weeding, fertilizer application and plant protection measures. The nursery beds should also be kept weed-free by frequent weeding. The most popular method of weeding in coconut nurseries is hand weeding, though it is labour intensive and time consuming (Remison and Mgbeze 1987).

During dry and hot weather, the nursery beds should be mulched and shaded with dry coconut leaves or any other suitable materials. Mulching with coconut leaves has been found to promote early and better germination, good growth of seedlings and recovery of high percentage of good seedlings (Liyanage 1952; Verghese et al. 1953; Aiyadurai 1954). Remison and Mgbeze (1987) observed that mulching helped to reduce competition from weeds and to conserve moisture, leading to increased plant height, plant girth and dry matter of seedlings.

Manuring of Nursery Seedlings Inorganic manures are usually not applied to the seedlings in the nursery as the intrinsic quality of seedlings is likely to be masked to some extent making a proper selection of seedlings difficult (John 1952). The seed nut contains adequate nutrients to meet the needs of the growing plant, at least up to the field planting stage. Maravilla et al. (1978) pointed out that the non-responsiveness of seedlings to manure application in the early nursery stages could be due to the availability of nutrients at sufficient levels to meet its growth requirements from the endosperm. However, as the nutrient reserve from the endosperm decreases from the fourth month after germination (Foale 1968b), the need for fertilizer application to the nursery has been stressed to produce healthy and vigorous seedlings, facilitating better establishment, faster growth and early bearing in the main field (Ziller and Fremond 1961; Fremond et al. 1966; Nelliat 1972; Mathew and Ramadasan 1964; Santiago 1978; Maravilla 1986; Srinivasa Reddy et al. 1998a).

The effect of N on the growth of coconut seedlings was more significant than P and K (Mathew and Ramadasan 1964). On the other hand, Bachy et al. (1962) observed in West Africa that excess N has a depressing effect on the growth of the seedlings. They reported that the application of P-K-Mg fertilizers gave a highly significant improvement in the vigour of the seedling. In Davao, it was observed that chloride application significantly increased the girth of the seedlings (Magat and Prudente 1974). It was also reported that application of KCl and NaCl to coconut seedlings influenced the growth and increased their resistance to diseases particularly leaf spots (Magat et al. 1977; Abad et al. 1978). Application of nutrients (N, P, K, Ca and Mg at 120:60:120:90:60 kg ha^{-1} $month^{-1}$) to the seedlings in the nursery bed has been found to be beneficial to produce seedlings with proper vigour and quality as indicated by higher chlorophyll content and nutrient concentration in leaves (Nelliat et al. 1976). In the Philippines, application of N and K fertilizers in coconut nursery produced taller seedlings with higher girth and greater vigour index (Almaden and Santiago 1980). Veloso and Ly (1982) also reported application of ammonium sulphate and NaCl at 30 g $seedling^{-1}$ produced taller seedlings with greater girth and lesser degree of leaf spot/blight disease infection compared to unfertilized seedlings. The collar girth, leaf area, dry matter production and number of roots were superior with the application of farmyard manure at 25 tonnes ha^{-1} and 160 kg each N and K fertilizers as soil application in three splits at fifth, seventh and ninth months after sowing (Srinivasa Reddy et al. 1998a). Embryo-cultured plantlets were significantly taller and had higher girth and more total leaves than unfertilized Laguna Tall and Makapuno seedlings, with application of NaCl at a total dose of 18–54 g seedling^{-1} and chicken manure at 250–750 g seedling^{-1} (at 2,4,6,8 and 10 months stage) (Ubaldo et al. 2006).

In order to develop a fertilizer mixture that supports the plant growth with simultaneous improvement of soil health in Sri Lanka, Ranaweera et al. (2010) evaluated inorganic fertilizers, organic manures (cattle manure and compost) and biofertilizers on 8-month-old coconut seedlings of CRIC 65 cultivar. They observed significant improvement in growth of seedlings as well as the soil microbial activity with application of Biogold® and compost. Application of organic manure (neem seed powder and leaves of gliricidia) and inorganic fertilizers also resulted in production of quality seedlings of Sri Lanka Tall variety in Pakistan (Solangi and Iqbal 2012). Application of NaCl at 50–60 g seedling^{-1} was recommended in the Philippines, and it has become a common practice for growing seedlings in the nursery (Magat et al. 1977).

According to Ho et al. (1978), monthly application of NPK fertilizers from the second month improved the girth of seedlings. Oguis et al. (1979) found that Cl significantly increased the girth of seedlings, while S greatly increased its height. Of the Cl sources, NaCl at 30 g Cl (60 g NaCl seedling^{-1}) gave the best result followed by KCl. They also found that 60 g Cl from KCl or higher rates of NaCl significantly reduced leaf spot incidence compared with higher rates of NH_4Cl. Maravilla (1986) also reported a beneficial effect of application of fertilizers for production of poly bag seedlings. Under Indian conditions, Ratnambal (1995) suggested application of 20 g $(NH_4)_2$ SO_4 and 25 g KCl 2 months after germination and 45 g $(NH_4)_2$ SO_4 and 45 g KCl bag^{-1} 4 months after germination as recommended in Indonesia. It is suggested that nursery manuring is not necessary if seedlings are removed 9 months after sowing. After this period, the seedling responds to manuring, especially if soil is of low fertility.

Irrigation of Nursery Irrigation is an important input for promoting early establishment and growth of freshly planted seedlings. The available moisture on the seed bed has been found to be the crucial factor facilitating germination (Wuidart 1981b). The nursery is to be watered twice a week or more often according to necessity during rainless periods. Peries and Everard (1995) noticed that the vigour of seedlings was enhanced by a good soil water supply during the early nursery stages combined with a higher level of solar radiation in the nursery site. Wuidart (1981b) suggested the following quantities of water every other day: 0–2 months 8 mm, 2–4 months 10 mm, 4–6 months 12 mm and > 6 months 15 mm. From 6 months onwards, the requirement will be about 75 m^3 of water day^{-1} ha^{-1} so that the hourly discharge of water should be about 10 m^3 ha^{-1}. The traditional method practised by farmers in some parts of India is to place earthen pots of 20 l capacity at a distance of 75 cm on either side of the seedling and filling the pots periodically with water, to provide sufficient moisture for establishment and vigorous growth of seedlings.

A modified system of raising seedlings is followed in some of the seed garden as follows:

Germination beds are used to obtain rapid germination and healthy, well-formed sprouts (Wuidart 1981a). The germinated ones are transferred to the nursey periodically. These beds should be as close to the nursery beds as possible, to reduce transport and the risk of drying out during transplanting. Placing nuts in a germination bed before planting out in the nursery has several advantages. In the germination bed, nuts can be planted much closer than in the nursery bed, saving space, water and labour. The soil should be friable and well-drained to facilitate the lifting of the seedlings for transplantation to the nursery and to reduce the risk of termite attack. Before placing the nuts in the germination bed, the soil should be weeded thoroughly. Spacing could be 5 cm between nuts in the row and about 20 cm between rows, using a density of about 16 seed nuts m^2. There should be more than 80% germination in 5 months with optimum management, and seed nuts that do not germinate by such time are to be discarded as failures (Harries 1983). The percentage recovery can be fixed at the sprouting stage itself, and all the ungerminated seed nuts can be disposed of (Pillai 1994).

Seedling Selection in the Nursery When the environmental conditions are favourable, seed nuts of tall cultivars commence to germinate 11 to 12 weeks after sowing. The percentage of germination reaches the maximum between the 17th and 18th week and then commences to decline. In India, nuts which do not germinate within 20 weeks from the date of sowing and dead sprouts are removed from the nursery.

The period between sowing and sprouting depends very much on the variety and may range from 3 to 6 months, the dwarf nuts sprouting earlier than those from tall variety. Early germinating and sprouting of seed nuts are related to high leaf production, early flowering and high yield. Rigorous roguing out of inferior seedlings in the nursery is as important as the selection of mother palms and seed nuts. Liyanage (1955), while analysing the results of a field trial in Sri Lanka to study the comparative effects of selection of seedlings, came to the conclusion that selection of seedlings alone will increase the crop yield by 10%. Later on Liyanage and Abeyawardena (1957) opined that in coconut, seedling vigour is highly correlated with adult palm characters such as early flowering, nut yield and copra production.

Fernando et al. (1993) studied the variation in seedling characters of 3 different coconut cultivars and their use in identification in the nursery. In general, the colour of the petiole and vigour of the seedlings can be used as selection criteria for dwarfs and hybrids. Seedlings of tall varieties usually grow tall with long leaves and long and broad leaflets showing late leaf splitting. The percentage of seedlings to be selected for planting differs depending on whether heterogeneous or homogeneous nuts are used for sowing. Where a comparatively homogeneous planting material is used, 65–70% good quality seedlings can be expected from a well-managed nursery (Nampoothiri et al. 2000). Details on selection of quality seedlings are given in Chap. 4.

7.2.6 Poly Bag Nursery for Superior Seedlings

Production of coconut seedlings in poly bags with suitable potting media was first introduced in 1969 at Côte d'Ivoire to produce vigorous seedlings with the advantage of early production (Wuidart 1981c). The method has many advantages such as facility for applying homogeneous and regular fertilizer doses leading to better seedling growth, easiness in handling the plants and providing seedlings with intact root system without damage for field planting (Foale 1968a; Chang 1978; Harries 1983; Srinivasa Reddy et al. 1996). The improved water-holding capacity of the potting medium would also help to maintain required moisture for early germination.

To derive the best benefits from the poly bag system, a pre-nursery is essential, wherein seed nuts are sown very closely and transplanted in poly bags when the sprouts are 8–10 cm long. The germinated nuts are taken out at weekly intervals until about 80% of the nuts are germinated or up to 5 months from sowing whichever is earlier. The germinated nut is placed in the half-filled bags with the sprout planted vertically in the centre of the bag and enough potting mixture is added to fill the bag up to two-third portion. Care must be taken to see that the collar of the young seedling is not covered by the potting medium.

The poly bag also facilitates prolonging the nursery period until the environment is conducive for field planting although no particular advantage has been obtained by planting older seedlings (Ho et al. 1978). In studies with different methods of raising seedlings in coconut nursery at the ICAR-CPCRI by Srinivasa Reddy (2000), better growth with higher number of roots and leaf splitting was observed in poly bags (14.5 roots and 9.1 split leaves per seedling, respectively) compared to the conventional bed nursery system (9.5 roots and 4.6 split leaves, respectively). The above-ground dry matter production of 12-month-old seedlings was also high (151.6 g seedling^{-1}) compared to 110 g seedling^{-1} in the case of bed seedlings. Unless seedlings are raised in close proximity to the planting site, the cost of transportation will be high. The extra labour and material costs will also be major constraints in production of poly bag seedlings. It is possible to accommodate 25,000 seedlings in a 1 hectare nursery area spaced at 60 cm × 60 cm in triangles.

Potting Media Preparation and Sowing of Seed Nuts Poly bags used for raising seedlings are made of 0.2 mm-thick black polyethylene (500 gauge), which are resistant to ultraviolet rays. Sufficient holes should be provided to drain excess water applied in the bags, but without the risk of the soil drying out. The poly bag usually takes about 16–18 kg of topsoil (Wuidart 1981c). On coastal clays, topsoil mixed with sand in the ratio of 3:1 is a suitable mixture for the poly bags (Ho et al. 1978). Researchers in the Philippines (Cano et al. 1989) have recommended the use of loose friable soil for potting coconut seedlings. The general potting mixture for raising coconut seedlings in poly bags in Sri Lanka is a 1:2:3 mixture of topsoil, cow dung and coir dust (Peries and Everard 1991). However, subsequent study by Perera et al. (1996) indicated that a mixture containing river sand, cow dung and coir dust (3:2:1) is the best. Among the materials which could be suitable for potting mixture, coir dust appears to be the best, considering the weight of roots, root anchorage and easiness in refilling the bags during different stages of seedling growth (Bandaranayake et al. (1997).

The study at ICAR-CPCRI, Kasaragod, India, indicated that sowing in potting mixture medium containing 1:1:1 mixture of red earth, cow dung and sand either in poly bag or cement tank was beneficial in producing vigorous seedlings (Srinivasa Reddy 1998). Since the potting mixture is not only costly, but its availability is also limited, the study on alternative media indicated that sand + vermicompost mixture in 1:1 proportion and sand + P + K + biofertilizer were similar in response to potting mixture media in terms of seedling growth, physiological parameters and final seedling vigour (Srinivasa Reddy et al. 2001). The seedlings raised in poly bags responded to salt at low rates of about 2 g as evidenced from increased girth, height and leaf number (Remison and Iremiren 1990). The plants tolerated higher levels of salt, but there was no significant increase in any of the growth parameters.

Laying Out of Poly Bag Nursery With the increasing size of the seedlings, spacing between bags is also to be increased. In a trial conducted in Nigeria, Iremiren (1986) found no difference in growth parameters between seedlings raised in poly bags and seedlings raised in the soil. In this case poly bag seedlings may not have shown any advantage, because the size of the bags was only 40 cm × 40 cm. Growth parameters were also similar at spacing treatments of 30 cm × 30 cm, 45 cm × 45 cm, 60 cm × 60 cm and 75 cm × 75 cm, except for height and leaf area index, which decreased significantly with wider spacing. The size of the nursery bed can be 3 m × 6 m with about 1.5 m spacing between beds. Each bed can accommodate 115 poly bag seedlings arranged in a triangular fashion with 60 cm between bags. Wuidart (1981b) recommended, as a general rule, spacing of 60 cm × 60 cm (up to 6 months), 80 cm × 80 cm (6–9 months) and 100 cm × 100 cm (9–12 months).

The seedlings removed from the nursery should be planted in the main field as early as possible, preferably within 10 days (Aiyadurai 1954). Seedlings in poly bags can be retained in the nursery for longer compared to seedlings planted in the bed nursery. Pruning of roots is not harmful in younger seedlings which are 7–12 months old, but may cause some delay in establishment and retard growth in older ones (Patel 1938).

7.2.7 Age of Seedlings for Transplanting in the field

Menon and Pandalai (1960) recommended that as a general rule, under normal conditions, seedlings of 9–18 months of age can be considered suitable for field planting in many places. At this stage, they will have about 60% of the kernel till left in the nuts as an available food reserve for the growing seedling, and this will facilitate their quicker establishment when transplanted out in the field. These seedlings do not wither quickly and being light in weight, can also be transported easily to other places. The optimum time for transplanting seedlings from the nursery to the field in Solomon Islands is 4–5 months after germination or when the seedlings have produced a total of 3–5 leaves (Anon 1967). In Fiji Islands also, seedlings with 3–4 leaves in the nursery are generally selected for transplanting in the field (Satyabalan 1976). Early transplanting of coconut seedlings from the nursery to the field has been recommended in almost all the coconut-growing countries to avoid the shock sustained during the removal of older seedlings from the nursery (Foale 1968c; Jenkin and Foale 1968; Sumbak 1968; Sumbak 1970; Anon 1977; Satyabalan 1983; Romney et al. 1968).

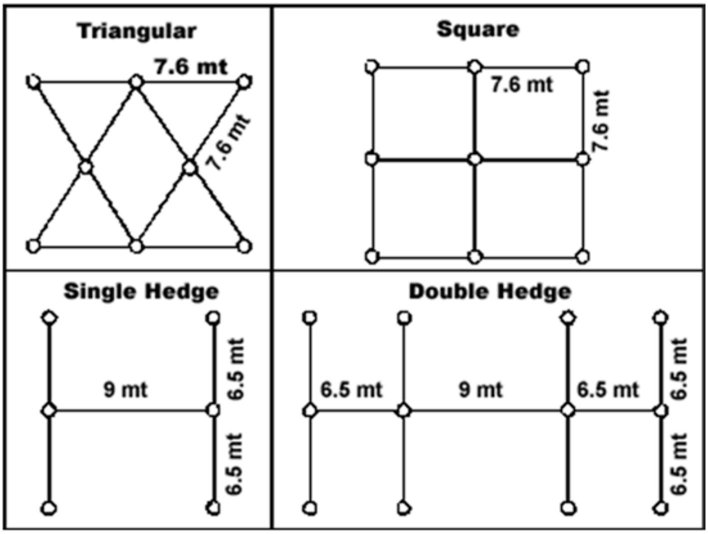
Thampan (1981) reviewed the different practices and norms adopted by the major coconut-growing countries and concluded that 6–9-month-old seedlings should be preferred for transplanting under normal conditions, since at this stage, the seedlings would have developed 3–5 fully opened leaves and a few roots with adequate availability of stored food in the nut. Satyabalan and Mathew (1983) and Satyabalan (1984) reported high and positive correlation of growth characters like collar girth and leaf production of the seedlings from the fifth month of growth of seedlings with those of the later months. This finding enabled them to identify palms of superior genetic value based on the growth characters of the progeny even from the fifth month. Remison (1987) recommended that seedlings should be transplanted after 9 months in the nursery in Nigeria. In India, for practical considerations, it is found to be ideal to plant 1-year-old seedlings, especially as it coincides with the monsoon. The coconut growers in Karnataka (India) prefer 3-year-old seedlings commonly known as *geppe* for planting in the main field rather than 9–12-month-old *molake* (Hanumanthappa et al. 2000). The steps involved for raising *geppe* seedlings include transplantation of 12-month-old seedlings from primary nursery to secondary nursery, where it is planted at a spacing of 1 m in trenches of 0.1 m^2. Farmers' preference to *geppe* seedlings is due to their better establishment and early bearing.

7.3 Field Planting

Adequate attention needs to be paid in land preparation like clearing, leveling, terracing and fencing before planting is taken up.

7.3.1 Field Planting Systems

The spacing to be adopted for planting coconut will depend upon the planting system, soil type and the type of cropping. Triangular, square, single hedge and double hedge are the common systems that could be followed. The hedge row system is based on narrow spacing between palms in the row and large spacing between rows. In single hedge system, the spacing could be 6.5 m within the row and 9 m between rows, whereas the double hedge row system is based on alternation of a narrow spacing (6.5 m) between two rows with a very wide spacing (9 m) between pair of rows.



The planting distance is generally in the range of 7 m × 7 m to 10 m × 10 m for tall cultivars, with an average planting density of around 130–180 palms ha^{-1}. A spacing as close as 5.5 m × 5.5 m is recommended for dwarf palms giving a density of 400 palms ha^{-1} depending on the planting system adopted (Friend 1990). Adoption of hedge (rectangular) system of planting coconut with wider row spacing and rows oriented in east-west direction would increase light availability and would facilitate growing annuals and perennials right from the time of planting coconuts. Triangular system of planting (equilateral triangle) accommodates 30 palms more than square system of planting. Multiplication of the number of palms obtained by square planting (at the same planting distance) by a factor 1.155 gives the approximate number of palms, which can be planted in triangular system (Abeyawardana 1954).

Whitehead and Smith (1968) in Jamaica, using Jamaica Tall variety on square system of planting at 6.6 m, 7.5 m, 9.0 m and 10.5 m, observed increase in nut yield $palm^{-1}$ from the closest (135 palms ha^{-1}) to the widest (85 palms ha^{-1}) spacing. Coomans (1974), from an experiment in Côte d'Ivoire with West African Tall coconuts planted at 26 densities ranging from 123 to 278 palms ha^{-1}, noticed effects of competition at higher densities, about 2 years before the palms came into bearing; leaf production was greater and flowering was earlier at the lower densities. The nut and copra yields $palm^{-1}$ decreased with increasing palm density. In these conditions, the optimal plantation density was 150 palms ha^{-1}. Comparison of the yield of West Coast Tall coconut palms planted at 6.6 m, 7.5 m and 9.0 m in triangular method to have densities of 150,200 and 250 palms ha^{-1} in Kerala, India revealed that the yield was the highest from plots with 250 palms ha^{-1} (Kannan et al. 1977). In Sri Lanka, significant differences were observed by Manthriratna and Abeywardena (1979) in the mean yield palm^{-1} for both between-row spacings and within-row spacings. They opined that as far as yield per unit area is concerned, the plant density matters rather than the 'rectangularity' of the system of planting. The number of nuts palm^{-1} decreased with increasing density with 83 nuts palm^{-1} at a density of 128 palms ha^{-1} to 54 nuts palm^{-1} at a density of 239 palms ha^{-1}. From a long-term trial on spacing and manuring (6.1 m × 6.1 m, 7.6 m × 7.6 m and 9.1 m × 9.1 m) with normal and double the recommended dose of NPK fertilizers in coconut palms (East Coast Tall) in Tamil Nadu, India, Louis et al. (1981) reported that though the growth characters were not affected by various spacings tried, there was forced vertical growth in the closest spacing tried. Though this also resulted in reduction of yield palm^{-1}, the yield ha^{-1} was increased due to the compensating effect of number of palms ha^{-1}. Studies by Fernando and Bandaranayake (1996) on the effect of planting density (128–239 palms ha^{-1}) on coconut yield in Sri Lanka indicated that nut yield palm^{-1} decreased with increasing density, but the yield maximized (2.26 tonnes ha^{-1}) at a density of 171 palms ha^{-1} and decreased beyond this. They concluded that density ranging from 171 to 179 palms ha^{-1} is the optimum for planting coconut in dry-intermediate zone.

Wickramaratne (1987) suggested that a rectangular system is the best for intercropping, whereas triangular system is ideal for coconut monocropping. The Coconut Research Institute of Sri Lanka (Anon 1987) recommended planting densities according to agroclimatic zone (and rainfall) with higher densities in the dry zone where intercropping is not recommended. Liyanage and Dassanayake (1993) suggested avenue planting system (e.g. 10 m × 5 m, 12 m × 5 m or 15 m × 5 m) with wider rows in east-west direction to facilitate better light penetration. In Indonesia, Darwis (1988) recommended new planting at 5 m × 12 m to have population of 160 palms ha^{-1} and wide interrow areas for cultivating other crops. Darwis (1990) indicated that the direction of coconut rows from east to west enables optimal use of sunlight, thereby minimizing shading of the intercrops.

Ovasuru (1988) reported that in Papua New Guinea, while coconuts were traditionally spaced at 7 m × 7 m to 9 m × 9 m, some new plantings have been taken up with wider spacing at 12 m × 12 m to accommodate intercrops such as cocoa. Intercropping experiments on cocoa with coconut conducted at Thailand, Dootson et al. (1987) indicated that triangular planting at 8.5 m may be a compromised option between the optimum for monoculture and the lower density appropriate for intercropping cocoa. In Tonga, traditionally coconut palms were planted on a 10 m × 10 m grid pattern (Thompson 1988). Some farmers adopt spacings of 5 m × 15 m to allow more light into the interiors to enable more crops to be grown beneath the coconuts. Opio (1990) discussed about 'hedge planting' which is based on wider spacing between the rows and closer spacing between the palms. Under such a system, though there is no significant difference in plant population per unit area compared to the conventional spacing of 9 m × 9 m, yields from hedge planting are generally higher, sometimes by as much as 25%. In Indonesia, the distance between the rows is normally much more than the distance between the palms in each row, creating adequate space for intercropping. This system could be developed with the same palm population as the traditional approach but with an option for intercropping. Research done by the Indonesian Coconut and Other Palmae Research Institute (ICOPRI) has shown that the combination of 6 m by 16 m (within and between rows, respectively) is an appropriate arrangement to allow successful intercropping (Novarianto and Warokka 2006).

7.3.2 Size of Pits and Planting of Seedlings

The type of soil decides the depth of pits to be taken for plating. In areas with laterite soil and rocky substratum, deeper and wider pits (1.2 m × 1.2 m × 1.2 m) are to be dug and filled up with topsoil, powdered cow dung and ash up to a depth of 60 cm before planting. Addition of 2 kg of common salt helps to loosen the soil in such areas. Arranging two layers of coconut husk, with concave surface facing up at the bottom of the pit before it is filled up, helps to conserve soil moisture in the pits. For planting the seedling, take a small pit at the centre of the filled pits (up to 3/4 depth of pit), keep the seedlings, apply fertile topsoil around it, press firmly and apply water around the seedling. Nelliat (1968) found that irrigation with 45 l of water once in 4 days combined with application of 0.15 m^3 of red earth in planting pits prior to planting in littoral sandy soil resulted in quick and vigorous growth of young palms. In loamy soils with low water table, planting in pits (1.0 m × 1.0 m × 1.0 m) filled up to 50 cm depth is generally recommended. However, in places where the water table is high, planting at the surface or even on mounds becomes necessary. Even under such cases, digging pits and filling have to be done. If planting is taken up in littoral sandy soil, application of 0.15 m^3 of red earth helps to improve the physical characteristics of soil. In areas subject to water logging, proper drainage is to be provided by making drainage channels. In Kuttanad region of Kerala, India, where below sea-level cultivation is done, planting of coconut seedlings is carried out on raised bunds.

7.3.3 Time of Planting

Planting the seedlings with the onset of pre-monsoon rains is ideal. In Kerala (India) and Sri Lanka, planting is undertaken in May–June with the onset of south-west monsoon. In places where assured irrigation is available, planting can be done at least a month before the monsoon sets in to allow seedlings to establish well before the onset of heavy rains. In areas liable to water logging, planting is taken up towards the end of monsoon. In Tamil Nadu and Andhra Pradesh (India), planting is taken up during north-east monsoon in October–November.

7.4 Care of Young Plantation

Availability of sunlight is one of the cardinal principles involved in farming and coconut is no exception. For enhancing the growth and photosynthetic efficiency of palms, which leads to early flowering, the seedlings should be planted in the open space. Ample sunlight, moisture and well-aerated soil are prerequisites for good establishment of coconut palms. The seedlings, after field planting, are to be protected from heavy wind by staking and from sunlight by proper shading. The palm base is to be kept mulched using coconut husk, dry leaves, etc. during the dry period to conserve soil moisture. Irrigation during summer months is necessary. In case soil happens to be covering the collar region and leaf axils, its frequent removal is necessary. The pits are to be widened every year before the application of manure and gradually filled up as the young plants grow. Necessary remedial measures should be taken up against diseases and pests as and when required. Please refer to Chaps. 10 and 12 for details.

7.5 Management of Adult Palms

The management practices to improve the productivity and to achieve sustainable production from coconut gardens include fertilizer application, green manuring/cover cropping, soil and water conservation measures, weed management, irrigation/fertigation, cropping/farming system and organic farming practices.

7.5.1 Fertilizer Application

Coconut is a crop that exports nutrients to the above-ground parts continuously from a limited volume of soil throughout its existence. The production phenology of coconut is such that once the palm starts flowering, it continues for decades (producing a spadix in the axil of each leaf every month), and therefore, the yield in coconut depends largely on the number of leaves produced per year. During these years, considerable quantity of nutrients is removed from the soil. It is, therefore, essential that a nutritionally rich environment is provided in the root zone of coconut all round the year to realize adequate yields. Soil test-based nutrient application will ensure judicious supply of nutrients.

Application of fertilizer would be necessary 3 months after transplanting (Sumbak 1970). ICAR-CPCRI has recommended that one-tenth of the dosage recommended for adult palms should be applied after 3 months of planting of seedlings in the main field, 1/3 after 1 year of growth, 2/3 after 2 years and full dosage from fourth year onwards. The general recommendation from the institute for fertilizing the adult palms is 500 g N, 320 g P_20_5 and 1200 g K_2 O palm^{-1} year^{-1} (Nelliat 1972).

Under average management of coconut gardens, a minimum of 340 g N, 170 g P_20_5 and 680 g K_2O palm^{-1} year^{-1} is to be given (Anon 1989). Fertilizers are to be applied within a radius of 1.8 m and forked in immediately. In the case of rainfed coconut cultivation, application of fertilizers, in general, is to be made in two splits every year, 1/3 of the recommended dose after the pre-monsoon showers and the remaining 2/3 applied in September when the south-west monsoon rains recede. However, in irrigated areas, application in more split doses is better.

Nutrient indexing of West Coast Tall (WCT), Chowghat Orange Dwarf (COD) x WCT and WCT x COD palms indicated that hybrid palms do not require higher N, P and K inputs for higher productivity. Studies on rationalization of P application to coconut palms indicated that if the soil test value is >20 ppm P, its application could be skipped (Khan et al. 1992). Application of magnesium at 500 g palm^{-1} is advantageous for root (wilt) disease-affected palms to improve the palm vigour (Cecil 1991). Boron deficiency causes characteristic malformation of leaves like hook leaves, nut cracking, drying of the female flowers and a number of other symptoms. Soil application of borax at 50 g palm^{-1} twice at monthly intervals after appearance of the first symptom corrects the deficiency (Baranwal et al. 1989). Please refer to Chap. 8 for details.

7.5.2 Green Manuring/Cover Cropping

Coconut is predominantly grown in sandy soils which often lack adequate quantity of organic matter and other major, secondary and micronutrients essential for growth and yield of coconut. The organic matter status of the soil can be maintained by the addition of green leaves, compost or farmyard manure (FYM). However, in many coconut gardens, farmers are unable to apply the required quantities of compost or FYM. Hence, cultivation of green manure crops in situ and their incorporation which is a very convenient and economic method of enhancing the organic matter status in the soil, is a viable alternative.

Green manuring involves growing of crops, mainly leguminous crops, and incorporation of green biomass when they attain the maximum vegetative growth. Leguminous green manure crops improve the soil structure and N status of the soil. In addition, they help in releasing plant nutrients, reducing leaching, regulating soil temperature and enhancing the activity of soil microflora. The nitrogen-fixing potential of legumes – *Rhizobium* symbiosis – can be exploited in the interspaces of coconut through intercropping of green manures, leguminous cover crops and forage legumes. Among the six green manure crops evaluated by Vijayaraghavan and Ramachandran (1989) in Tamil Nadu, India, *Desmodium tortuosum* was the best which produced 12.8 kg of green leaf matter basin^{-1} followed by cowpea (*Vigna unguiculata*) and sunn hemp (*Crotalaria juncea*). The dry matter production was also found to be superior in *Desmodium* compared to others.

In trials on alley cropping of *Leucaena* as one or two double-row hedges between two rows of coconuts in Western Ghats of India, dry matter and organic N from seven prunings of *L. leucocephala* could meet the requirements for green manure and mulching materials for coconut gardens (Vijayakumar et al. 1986). A series of experiments on *L. leucocephala* conducted in Sri Lanka showed that the highest biomass yield (13.4 t ha^{-1} $year^{-1}$) was obtained in the dry zone on entisols with a pH of 6.0. Application and incorporation of 30 kg coconut $palm^{-1}$ of fresh loppings of *Leucaena* as a green manure around the palm provided the entire N and 20% of P and K requirements of an adult palm (Liyanage et al. 1993a). Application of fresh *Leucaena* loppings in a quarter circle trenches around low-yielding palms on degraded ultisols resulted in 29% increase in nut production and 51% increase in copra yield.

Gliricidia sepium lopping is an ideal green manure for coconut palms that supply significant amounts of N. It is moderately shade tolerant and performs well in acid soils where *Leucaena* does not. A well-established gliricidia intercrop is capable of producing about 8–10 mt ha^{-1} of fresh loppings from three prunings $year^{-1}$. Application of at least 30 kg lopping around each palm can completely replace inorganic N input and about 20% of P and K requirement of coconut (Liyanage 1994). In addition, *G. sepium* can enrich the subsoil through N fixation and mining nutrients from subsoil with its deep root system. *G. sepium* could be successfully grown as an intercrop in the coconut garden in littoral sandy soil also for green manure production (Subramanian et al. 2000). Three rows of *G. sepium* in between two rows of coconut palms with three prunings $year^{-1}$ resulted in the best biomass yield (7970 kg ha^{-1}). Results showed that application of *G. sepium* prunings to the coconut palms could meet a major portion of N (90%) and part of the P and K requirements (25 and 15%, respectively) of coconut palms.

Solangi et al. (2010) studied the usefulness of *G. sepium* in coconut plantations of Pakistan and found that providing about 30 kg of leaves on the surface as mulch provided sufficient N, P and K for coconut. Ilangamudali et al. (2014) reported accumulation of soil organic matter due to incorporation of *G. sepium.* Higher total N, exchangeable K and Mg as well as higher soil microbial activity observed under such cases will be helpful to improve soil fertility of degraded coconut lands in intermediate and dry zones of Sri Lanka. Lekadou et al. (2012) studied the effect of spatial arrangement and population density of *Acacia auriculiformis* trees with coconut palms grown in littoral quaternary sands in Côte d'Ivoire. Though the initial growth of coconut palms (up to 3 years) was better in sole coconut gardens, its subsequent growth (5 years after planting) improved when pruning of *Acacia* and application of leaves were done. This also improved the N, P and K status. However, *Acacia* pruning should be done only 3 years after planting to reduce the depressive effects on coconut palms.

In cover cropping a semi-permanent vegetation of leguminous creepers is maintained in the interspaces of perennial tree crops. It helps in preventing soil erosion and weed growth and adds organic matter and acts as thick mulch which in turn improves soil fertility and water-holding capacity. The choice of cover crop depends on climate, soil as well as age of palms (Bourgoing 1990). Among the four leguminous crops (*Atylosia scarabaeoides, Pueraria phaseoloides, Centrosema pubescens* and *Calopogonium mucunoides*) evaluated for their microbial indices and relationships in a 19-year-old coconut plantation in South Andaman Island (India), Dinesh (2004) found that the latter two were better suited as cover crops due to their positive contribution to soil organic carbon, N and microbial activity. From another study, Pandey and Begum (2010) also observed that growing *Pueraria* as cover crop in coconut plantation increased the soil N mineralization rate, mineral N pool and microbial biomass carbon by 37, 46 and 41%, respectively. In areas where P levels are low, in order to get optimum benefits out of *Pueraria phaseoloides* (effective ground cover and increased nodulation for N fixation), it is necessary to apply phosphate fertilizer (Wijebandara 2010).

The technique for utilization of leguminous cover crops as green manures to supply biologically fixed nitrogen and easily decomposable biomass to coconut was standardized (Thomas and Shantaram 1984). It involves cultivation of leguminous creepers such as *Pueraria phaseoloides*, *Mimosa invisa* and *Calopogonium mucunoides* in coconut basins during the monsoon period from June to October and incorporation of the legume biomass in respective basins. During a growth period of 140–150 days, the legumes yielded 15 to 28 kg of biomass and 102 to 197 g of N in the basin of a coconut palm. Legumes such as cowpea, sunn hemp, etc. can also be cultivated in coconut gardens to generate large quantities of biomass for recycling.

7.5.3 Soil and Moisture Conservation

The coconut palm, which exhibits simultaneous vegetative and reproductive phases of growth, requires a regular supply of water to realize and maintain its potential growth and nut production. As it is generally cultivated under rainfed conditions, soil moisture stress during the non-rainy seasons is an acute problem, particularly in sandy or gravelly soils. During extended periods of soil moisture stress, the cells of the absorption zone of coconut roots were found to be inactive by suberization and dehydration, thereby adversely affecting the water and nutrient absorption processes (Vidhana Arachchi 1996a, Vidhana Arachchi et al. 2000). Soil moisture stress is known to affect the growth of young palms, delay initiation of flowering, increase shedding of buttons and immature nut fall as well as reduce the number and size of nuts (Abeywardena 1981).

For reducing surface evaporation and improving water retention under rainfed conditions and reducing ill effects of soil erosion, various conservation methods such as (i) mulching with coconut husk, coir dust, green leaves, dried coconut leaves, etc., (ii) addition of organic manures such as FYM or green leaf manure, (iii) coconut husk burial (effect lasting for 7 years), (iv) inter-cultivation and (v) bunding/terracing are to be adopted.

Mulching is a simple agro-technique of practical significance to reduce soil moisture loss and to create suitable agroclimatic conditions for proper growth of plant roots and soil flora and fauna. Organic materials from plantations having high moisture holding capacity are ideal for spreading in coconut basins before the withdrawal of monsoon when sufficient moisture is available in soil. Mulches decompose over a period of time and add to the soil organic reserves.

Coir dust, which is a major by-product in coconut fibre industry, could be used to maintain and improve the organic matter content of depleted soils (Vidhana Arachchi and Jayasekara 1988). Coir dust, being a spongy material, absorbs ample quantity of water compared to its weight (Liyanage 1988; Vidhana Arachchi and Jayasekara 1988; Vidhana Arachchi and Somasiri 1993; Van Holm 1993). In gravelly soils, 20% increase in nut yield and 15% increase in copra yield were observed as a result of burying coir dust. Vidhana Arachchi and Somasiri (1997) suggested application of 21 tonnes of coir dust ha^{-1} (6.3% or 1:15 coir dust/sand; vol/vol) in sandy soil to improve moisture and nutrient retention capacities and physical properties.

Coconut husk, a biodegradable material and because of its plentiful availability in tropical and subtropical regions, has very good potential as resource for environmentally friendly agricultural purposes. Das et al. (1991) reported 50% increase in yield after incorporating coconut husks as mulch to the basin of coconut palms. Manufacture of soil erosion control materials from coconut husk fibre was introduced in the middle of nineteenth century (Ziegler and Sutherland 1997). Sutherland and Ziegler (2007) reported that natural fibre rolled erosion control systems are applied on bare slopes as they are biodegradable, less costly, environmentally friendly and equally effective in reducing erosion and generally provide a favourable microclimate for biomass production. Utilization of coconut fibre mat or geotextile as buffer zones on bare soil is found to be highly effective in reducing runoff and mitigating soil losses.

Liyanage et al. (1993b) and Abeygunawardena et al. (1995) concluded that soil moisture conservation, using coconut husk and coir dust in lateritic gravel and sandy soils, is an economically viable proposition. Vidhana Arachchi (1996a, b) found that 75–80% of effective roots of adult coconut palm was localized in a depth range of 20 cm to 80 cm. Neutron probe study also corroborated the result indicating that such roots were more responsible for extraction of water from the soil profile. Only about 5% of roots went beyond 100 cm depth. The maximum absorption took place within a distance of 1 m away from the palm, and therefore, the placement of any soil moisture conservation measure should target the effective root zone.

Integration of vegetative (intercropping) and engineering measures was found to be effective for soil and water conservation in coconut plantations located in sloppy areas (Dhanapal et al. 2002). Contour trench (4 m length × 0.5 m width × 0.5 m depth) filled with coconut husk with two lines of pineapple in the interspaces of coconut proved to be the best for soil and moisture conservation in a laterite soil having a slope of 14–16%. This also minimized loss of soil. The inter-cultivation of CO-3 grass (hybrid of Bajra x Napier grass) not only reduced runoff but also produced fodder at 100 tonnes ha^{-1} $year^{-1}$ in eight harvests. The highest increase in coconut yield (162%) was observed in the same treatment where the annual nut yield was increased from 35 nuts $palm^{-1}$ to 93 nuts $palm^{-1}$. Among the various soil and water conservation technologies such as half-moon bund, coconut husk burial, filling trenches with coconut husk, mulching, providing cover crops and catch pits adopted by farmers, mulching coconut basins with leaves, or coir pith was more advantageous compared to other soil and water conservation technologies (Thamban et al. 2014).

Coastal sandy soils suffer from poor retentive capacity for water and nutrients. Besides, they also show excessive infiltration due to the porosity of sand, easy leachability and low inherent fertility status. These problems could be overcome by adopting certain agro-techniques such as preparing trenches or pits in between coconut rows and filling with coconut husk or raw coir pith to 5 cm height (Subramanian et al. 2006).

7.5.4 Irrigation

One of the critical resources required in coconut production is the availability of water. Though most of the coconut-growing regions are endowed with high rainfall, the rainy period is confined to a few months during the monsoon season. The palm experiences moisture stress and drought conditions for varying periods extending up to 7 months in a year. The adverse effect of moisture stress on the productivity of coconut has been well established. Utilization of the available water in the most effective manner by optimizing irrigation schedules and by adopting soil moisture conservation practices and water harvesting techniques assume particular significance in coconut cultivation. According to Prasada Rao (1986), drought produces injuries to leaves of coconut palm and reduces the yield for several months. Proper irrigation management of coconut palms leads to maximum productivity and continuous nut harvest.

In coconut, initiation and differentiation of vegetative and reproductive primordia and enlargement of cells are very sensitive to moisture stress. Severe drought results in drooping of leaves, breaking of petioles and even death of palms. Even in the well-managed fields, drought affects the nut yield up to 30% in the succeeding year. Rao and Vamadevan (1982) have shown that moisture stress period varies between 14 to 15 weeks in southern parts and 18 to 21 weeks in the northern parts of Kerala, India. Yusuf and Varadan (1993) summarized the results of water management studies conducted on coconut by various research workers in India.

7.5.4.1 Water Requirement and Response to Irrigation

In order to maintain the optimum level of water in the plant biomass and to determine the frequency of irrigation, the assessment of water requirement is essential. Crop water requirements are expressed by the rate of evapotranspiration (ET) in mm per day. The evapotranspiration (Eo) together with the crop coefficient (Kc) gives the water requirement of the crop. Joshi et al. (1988) reported that the water requirement of coconut for optimum growth is 20 mm of water at IW/CPE ratio of 1.0. Rajagopalan et al. (1988) also observed the same in the case of young West Coast

Tall x Gangabondam (T x G) coconut hybrids, when the palms were irrigated at 30 mm cumulative pan evaporation (CPE). The evapotranspiration rates of 5-year-old coconut palms (cv. West Coast Tall) grown in an Oxisol on the west coast of Kerala (determined by soil moisture depletion studies and lysimetric measurements) increased from 2.9 mm day^{-1} in December to 5.5 mm day^{-1} in April and decreased to 2.3 mm day^{-1} in June following the onset of monsoon rain (Rao 1989). Jayakumar et al. (1988) measured the consumptive use of water in 6-year-old irrigated palms (*cv*. West Coast Tall; leaf area index 2.4) over a 6-month dry period from November 1986 to May 1987. They reported the consumptive use of water to range from 2.7 to 4.1 mm day^{-1}. The crop coefficient values were 0.54, 0.73, 0.60 and 0.65 by the Penman, Blaney-Criddle, radiation and US Class-A pan methods, respectively. Saseendran and Jayakumar (1988) computed the mean yearly consumptive use of coconut to be 1126 mm (37 1 palm^{-1} day^{-1} for a basin area of 1.2 m^2). The yearly irrigation requirement was estimated to be 4656 1 palm^{-1} spread over the non-monsoon months of December to May. A stepwise multiple linear regression equation fitted to the coconut productivity and monthly rainfall data for Kerala state for the period from 1956–1957 to 1989–1990 indicated that coconut yield increased as a result of summer rains in March and May (Babu et al. 1993). The irrigation requirement of coconut worked out (using the reference evapotranspiration) varied from 1106 l in December to 13,91 l palm^{-1} month^{-1} during May and the total irrigation requirement for 6 months being 7807 l (Rao 1994).

Soil- and climate-based irrigation schedule study for coconut in Kerala, India, indicated that requirement of water varied according to the type of soil (Salam and Mammen 1990). Based on yield trends and irrigation water consumption, irrigation at 50 mm CPE (cumulative pan evaporation) with 50 mm water was suggested as the best schedule for irrigating West Coast Tall coconuts during dry spells in the west coast in Kerala (Jose Mathew et al. 1996). Yields became stable with adequate irrigation showing minimum fluctuation among harvests during different periods of the year. A comparison of different irrigation treatments with mature tall palms growing in a sandy clay loam/clay soil with a low water table (below 5 m throughout the period) indicated that the best results in terms of yield and economic water use were obtained with 50 mm water at 50 mm Epan (Mathew et al. 1993a). The annual irrigation and water requirements, during the non-rainy period, were determined as 538 mm and 1093 mm, respectively. The consumptive use during this period was estimated at 272 mm with irrigation: CPE ratio of 1.02.

In Sri Lanka, Vidhana Arachchi (1998b) formulated criteria for the design of a drip irrigation system for coconuts. Roots at a distance of 0.5 to 1.0 m away from the base of the palm were responsible for most of the water absorption, and the highest moisture extraction was observed at 1 m distance. The maximum flow rate recommended was 30 l ha^{-1} for 2.5 h from each of the four drippers placed equidistant in the circumference of a circle of radius 1 m around the base of the trunk. The evapotranspiration rate of 15-year-old coconut palms (cv. CRIC 60) during the dry period was 2.52 ± 1.12 mm day^{-1}, and therefore, irrigation frequency for coconut grown in drought-prone gravelly soils of the Andigama series (Red Yellow Podzolic) was determined to be 8 days.

Using a soil water balance approach, Azevedo et al. (2006) estimated actual evapotranspiration (ETc) of 6-year-old dwarf green palms grown on sandy soil in Northeast Brazil over a 2-year period. The irrigation treatments were 50, 100 and 150 l palm^{-1} day^{-1} equivalent to 1.0, 2.0 and 3.0 mm day^{-1}, respectively, applied using two sprinklers positioned at 0.8 m apart from each palm, which works out to 2.5, 2.9 and 3.2 mm day^{-1} with cumulative annual totals of 900 mm to 1100 mm at a planting density of 205 palms ha^{-1} (triangular system at 7.5 m). These are equivalent to 120 l to 160 l palm^{-1} day^{-1}. There were no yield differences between treatments in terms of the number of bunches palm^{-1} or the number of fruits bunch^{-1}, but extra irrigation water increased the volume of water nut^{-1} by about 16%. When yield was expressed as the number of nuts ha^{-1}, there was a significant 12% yield loss from applying 1.0 mm day^{-1} compared with 2 mm day^{-1} (equivalent to a reduction in the number of nuts palm^{-1} from 93 to 82). Water-use efficiency (WUE) values decreased with increasing irrigation water level for all productivity parameters.

In a detailed experiment in Vanuatu, Roupsard et al. (2006) monitored water use of Vanuatu Red Dwarf x Vanuatu Tall Hybrid over a 3-year period in a typical coconut plantation, displaying a constant leaf area index (LAI = 3) and a grass understorey. The eddy flux method was used to estimate actual evapotranspiration (ET) from the palms and grass understorey and the sap flow method to measure transpiration (T) from the palms alone. The annual transpiration was 642 mm (ranging monthly between 1.3 and 2.3 mm day^{-1}), amounting to around 68% of E. ET rates varied seasonally between 1.8 and 3.4 mm day^{-1} and ETo (Penman-Monteith) from 2.4 to 5.8 mm day^{-1}. At a density of 144 palms ha^{-1}, these ET values equate to 93 to 160 l palm^{-1} day^{-1}. The crop coefficient Kc values averaged 0.79 and 0.59 in the cool and warm seasons, respectively.

From the studies in the coastal region of Ceara, Brazil, Miranda et al. (2007) derived Kc values for micro-sprinkler irrigated dwarf green coconut palms over a 32-month period, commencing 11 months from planting. Using the water balance approach (based on tensiometers), ETc increased from a minimum of 0.52 mm day^{-1} (25 l palm^{-1} day^{-1}), at the 11th month after planting, to a maximum value of 5.01 mm day^{-1} (244 l palm^{-1}day^{-1}), at the 36th month after planting. Over the same period, ETo (Penman-Monteith) varied between 3 and 6 mm day^{-1}. During the canopy development phase, Kc increased linearly from 0.63 (11 months after planting) to 1.0 (23 months, when the palms were flowering). During the flowering and fruit development stage, the average Kc value was 1.02.

Madurapperuma et al. (2009b) used the ‘compensation heat pulse method’ (which has been successfully evaluated on palms in Australia by Madurapperuma et al. (2009a)) to measure actual water use of mature palms (20 years old) of two cultivars grown on two contrasting soils in Sri Lanka planted in square system with a spacing of 8.3 m × 8.3 m (145 palms ha^{-1}). Peak rates of water use differed between the two cultivars, reaching 13 to 14 l palm^{-1} h^{-1} for CRIC 60 (a tall x tall hybrid) but only 9 to 10 l palm^{-1} h^{-1} for CRIC 65 (a dwarf x tall hybrid). Total daily water use averaged 120 l palm^{-1}day^{-1} (ranging from 105 to 135 l palm^{-1} day^{-1}) or 1.74 mm day^{-1} for CRIC 60 and 25% less at 90 l palm^{-1} day^{-1} (ranging from 75 to 97 l palm^{-1} day^{-1}) or 1.31 mm day^{-1} for CRIC 65. The mean daily ET rate over the period of measurement was 3.5 mm giving a Kc value of 0.37 to 0.50. Palms growing on the water-retentive soil had larger leaf areas and trunk diameters (and hence more stem water storage) than the corresponding palms grown on the second soil. In Sri Lanka, CRIC 65 is known for its sensitivity to water stress, while CRIC 60 is recognized as being drought tolerant.

Yield responses to irrigation have been recorded in field experiments in Kerala, (India), Sri Lanka and Brazil. Dhanapal et al. (2000a) reported that irrigation increased the root production in coconut palms in India, which is considered important from the point of view of increased WUE as well as better nutrient absorption. More main roots were produced from one-fourth of the basin area in irrigated palms (1149–1212) compared to that in rainfed palms (429).

The irrigation requirement of young palms (from 5 to 7 years; cv. WCT) was reported by Nelliat and Padmaja (1978) in Kerala. The best treatment in terms of yield of nuts and water use efficiency was the application of 40 mm of irrigation water during December to May (IW/CPE ratio of 0.75). In this way, an average total of 680 mm of water was applied in the summer months, yielding a total of 157 nuts palm^{-1} over the 3 years after the palms came to bearing. By comparison, when the IW/CPE ratio was 0.5, the total yield was significantly less, at 126 nuts palm^{-1}. Bhaskaran and Leela (1978) conducted a trial in red sandy loam soil for 12 years with cv. WCT. Four categories of palms, based on yield per palm (poor, < 20 nuts; low, 20 to 40 nuts; medium, 40 to 60 nuts; and high, 60 to 80 nuts), were selected for the study. Water was applied at 800 l palm^{-1} once in a week (equivalent to 2 mm day^{-1}) in 2 m radius basins during the summer months (December to May). The maximum yield increase of 25.9 nuts in transition period (initial 3 years of the study) was recorded by 'low yield group' closely followed by 'medium yield group' recording an increase of 23.4 nuts. 'High yield group' recorded comparatively low increase in yield (12 nuts). This yield increase was mainly attributed to high setting and high female flower production as nuts from the newly formed bunches will be ready for harvest only after 3 years. Further assessment of 8 years' yield revealed an annual yield increase of 9, 13, 8 and 12 nuts for 'poor', 'low', 'medium' and 'high' yield groups, respectively. The average increase over 11 years from the commencement of irrigation was also maximum in 'low yield group' (38.3 nuts) followed by 'medium group' (32 nuts).

Shanthamalliah et al. (1978) reported that irrigation at 80–100% or 60–100% of available soil moisture, providing 15 cm-thick coir dust mulch, resulted in maximum number of leaves and increased girth of stem. The total water requirement was 1591 mm and 1533 mm year^{-1} for maintaining 80–100% of field capacity and 60–100% of field capacity, respectively. Mulching with coir dust reduced water requirement by about 40–55%.

Nair et al. (1988) reported the results of an irrigation trial for cv.WCT in which water was applied at 500 l palm^{-1} in a sandy clay loam soil at different intervals during the summer months (December to May) over a 5-year period. Compared to the control (rainfed), significant increase in yield was obtained from the third year on irrigating palms when the CPE totalled 50 mm. The B/C ratio was the highest (1.50) in drip irrigation at 100% Eo followed by 66% Eo (1.42), and the water saving of the latter was 34% over the former and 43% over basin irrigation (IW/CPE ratio of 1). The annual yield increase of 30–40 nuts palm^{-1} was reported from mature coconut palms (cv. WCT) over a 6-year period as a result of irrigation (Naresh Kumar and Kasturi Bai 2009). In Aliyar Nagar, India, basin irrigation at 4 cm depth and drip irrigation at 100% of Eo generally gave the highest values for total leaf production, number of spadices, number of female flowers and higher nut yields in hybrid coconut than the other irrigation treatments (Venkitaswamy et al. 1997). Studies on the effect of mulches and irrigation on young coconut plants in coastal Karnataka, India, indicated better growth due to drip irrigation and coir pith mulch (Uthaiah et al. 1993). Hybrids (D xT) planted in a dry climate with supplementary irrigation and NPK fertilizers gave copra yields of 4.1–4.3 tonnes ha^{-1} year^{-1} during 8–16 years compared to 3.4–3.6 tonnes ha^{-1} year^{-1}, when management input was lower (Daniel et al. 1991).

Irrigation with 20 l of water applied twice a week or two earthenware pots buried on either side of the plant and filling them twice a week (27 l week^{-1}) resulted in better establishment and vigorous growth of the young seedlings (cv. CRIC 60) in the dry zone of Sri Lanka (Liyanage and Mathes 1989). From a 3-year trial with 3 coconut cultivars, viz. Malayan Yellow Dwarf, Malayan Green Dwarf and Malayan Red Dwarf (13–16-year-old palms), it was reported that irrigation on alternate days was highly effective to enhance the yield compared to irrigation at fortnightly intervals (Louis et al. 1980).

More than four decades of research in Sri Lanka has indicated that the cv. CRIC 65 was capable of producing a sustained higher yield than cv. CRIC 60 in the absence of adverse soil water deficit (Peries 1995). The cumulative yields of nuts and copra were 50% higher in CRIC 65 than in CRIC 60 over a period of 32 years. Development, precocity and production of dwarf coconut palms varied under different irrigation frequencies varying from 6 to 28 l palm^{-1} day^{-1} (Miranda et al. 1999).

7.5.4.2 Methods of Irrigation

Irrigation methods commonly adopted in coconut gardens are flooding, basin irrigation, sprinkler or perfo spray and drip irrigation.

Flood Irrigation In this method of irrigation, water is allowed to flood the land surface under coconut. Flood irrigation was the most common method practised before the micro systems of irrigation were introduced. However, this method of irrigation is still in use only in some of the coconut-growing areas. There are many problems associated with this type of irrigation such as (1) large quantity of water required for meeting the water requirement of the palms; (2) deep percolation of water and leaching of the nutrients away from the root zone, especially in areas with highly porous soil; (3) difficulty in farm operations especially if the soil is too heavy as in clay soil; (4) non-uniform wetting; (5) increased cost for electricity; and (6) requirement of special land preparation like land leveling and provision of irrigation channels. The quantity of water required will be around 0.75 l to 1.00 lakh l day^{-1} ha^{-1}

which is generally given only once in a week or 10 days. In littoral sand, significant increase in functional leaves and yield were recorded under flood irrigation (Bhaskaran and Leela 1978), with an estimated cost-benefit ratio of 1:3.

Basin Irrigation In basin irrigation, water is applied to the basins of 1.8 to 2.0 m radius around the trunk which is the active root zone of coconut. Irrigation channels are provided in between two rows of coconut, and each basin is connected with the channel. In this method, there will be loss of water due to deep percolation, seepage and evaporation. This loss can be reduced by irrigating the basin through hose pipes. However, there is no control over the flow of water. The main advantages are (1) saving in quantity of water compared to flood irrigation as only limited area is irrigated and (2) application of more uniform quantity of water. Irrigation with 200 l of water once in 4 days in the basin of coconut grown in red sandy loam soil has been recommended for adult palms (Nelliat and Padmaja 1978). Nair et al. (1988) reported that irrigating coconut with 500 l of water in basins at cumulative pan evaporation (CPE) value of 50 mm at an interval of 12 days was economical. A 7-year study with basin irrigation during dry periods at 373 l palm^{-1} weekly or fortnightly, or at 745 l palm^{-1} fortnightly, indicated that total copra yield increased from 1.59 tonnes ha^{-1} to 2.44 tonnes ha^{-1} by weekly applications in drier years and from 2.28 tonnes ha^{-1}to 2.87 tonnes ha^{-1} in wetter years (Abeywardena 1981). The disadvantages of this system are the following: (1) more water is required compared to drip irrigation; (2) there is a chance of deep percolation and wastage of water, especially in porous sandy soil; and (3) there is increased weed growth in the basin area.

Sprinkler or Perfo Irrigation Sprinkler irrigation or perfo sprays are most suited for inter or mixed cropping systems where the entire surface requires wetting. Perfo irrigation is a kind of sprinkler irrigation where small holes are formed throughout the pipe through which water is forced out in small sprinkle and wets the gardens. To wet a 1 hectare garden, approximately 200–300 m of aluminium pipes are required.

The advantages are as follows: (1) an ideal microclimate is maintained in the garden, (2) uniform wetting of the soil, (3) intercrops irrigated along with the main crop and (4) best suited for high-density multispecies cropping system. Irrigation efficiency is also high in this method compared to basin and flood irrigation. However, this method requires higher initial investment; sediment in the water may clog the small pores and affect the irrigation; it is difficult to create the required moisture stress for some of the crops, which are grown along with coconut (coffee, pepper), since the system works on high pressure and the pump should work continuously; there is a chance of water being carried away in drift form if the area is open and experiences heavy wind; and there will be more weed growth as the whole garden gets wet.

Liyanage et al. (2008) tested girdle sprinkler system, which is a new approach for irrigation of coconut. It comprises of 1 kg cm^2 inlet pressure with sub-mainline having 20 mm PVC laterals. While it had 94% distribution uniformity, similar system with 16 mm conduit laterals showed 91% distribution uniformity, which could be considered as an excellent system. This system helps to conserve water as well as labour compared to hose irrigation. It also has less clogging problems compared to drip irrigation so that even harvested rain water or water with silt particles could be used to irrigate with just a screen filter.

Drip Irrigation (Trickle Irrigation) Drip irrigation, a micro-irrigation system, is an efficient method of providing irrigation water directly to the root zone of plants facilitating watering close to the crop as per its requirement. The system applies water under pressure at a low rate to keep the soil moisture within the desired range. The system has an overall application efficiency of 90% as compared to 25–30% for surface irrigation. It is ideally suited for widely spaced crops like coconut as it saves water, energy and labour and WUE is high. It can be adopted in any type of soil especially in very porous soils and land with undulated topography where any other type of irrigation can lead to lot of wastage of water and energy.

The characteristic features of drip irrigation (trickle irrigation) method are as follows: (1) low rate of application, (2) application of water over a long period to meet the water requirement of the crop, (3) application of water at frequent intervals to suit the infiltration rate avoiding wastage of water and (4) application of water near or at the root zone of palms.

A study conducted in Kerala indicated that yield of coconut with drip irrigation at 30 l palm^{-1} day^{-1} during January to May was comparable to basin irrigation at 600 l palm^{-1} week^{-1}, achieving 66% saving of water (Varadan and Chandran 1991). Experiments to evaluate the influence of drip irrigation in comparison with surface (basin) irrigation in Tamil Nadu, India, revealed that irrigation methods had a significant effect on nut yield (Subramanian et al. 1997). Drip irrigation at 40 l palm^{-1} resulted in a saving of 40% of water compared with surface irrigation with nut yields comparable to those produced with surface irrigation. In a low rainfall area in Tamil Nadu, India, the monthly water requirement of a coconut palm irrigated with drip irrigation ranged from 55 l day^{-1} in December to 115 l day^{-1} in June (Kulandaivelu 1990). A trial conducted to evaluate the economic viability of drip irrigation in a full-bearing coconut plantation in Gujarat, India, indicated that it can save 45–50% water over surface irrigation without any significant reduction in yield (Kapadiyal et al. 1998).

In drought-prone gravelly soils of the Andigama series (Red Yellow Podzolic) in Madampe, Sri Lanka, irrigation through four drippers placed equidistant in the circumference of a circle of radius 100 cm around the base of the palm and discharging water at 30 l h^{-1} for 2.5 h wetted a large volume of soil in the effective root zone (Vidhana Arachchi 1998a). Nainanayake et al. (2008) evaluated the response of 20-year-old palms (grown on a shallow (0.6 m) sandy clay loam soil) to drip irrigation over a period of 2–4 years. Irrigation lowered the temperature of the canopy microclimate and the nut surface temperature, thereby reducing the possibility of empty nut formation during dry spells. Irrigation also increased female flower production and reduced immature nut fall. Over a 2-year period, application of 80 l of water palm^{-1} day^{-1} resulted in a 45% yield increase over the control. Reducing the quantity of water applied by 50% (40 l palm^{-1}; 0.65 mm day^{-1}) reduced the yield benefit to 20%.

Drip irrigation along with mulching will be a useful practice with regard to both soil moisture conservation and soil temperature regulation in case of littoral sandy soil. It has been reported from India that the available soil moisture was higher by 22.2 to 28.8% in the drip irrigated basins under mulch compared to drip without mulch. Similarly, there was a reduction in the soil temperature under irrigated, mulched plots by 1.6–1.7 °C compared to un-mulched rainfed plots at 15 cm depth (Maheswarappa et al. 1998b). The mean yield under drip irrigation was 73.3 nuts palm^{-1} under mulching, whereas it was only 58.8 nuts palm^{-1} without mulching indicating the beneficial effect of mulching along with drip irrigation. The pooled data on nut yield for 4 years did not show any significant difference between drip and basin irrigation treatments in littoral sandy soil. The nut yield under different irrigation treatments was on par with each other but was significantly superior to that of rainfed control (26.8 nuts palm^{-1} year^{-1}) (Dhanapal et al. 1998). The benefit/cost ratio in the drip irrigated coconut garden was 2.02 as compared to 1.68 under basin irrigation and 1.07 in rainfed gardens. In addition, the payback period for this investment on the drip irrigation system was only 2 years, thus confirming the economic viability of drip systems for coconut gardens. Through adoption of drip irrigation system, 80 man-days of labour ha^{-1} could be saved compared to the conventional basin irrigation system. Bastine and Palanisami (1998), based on the analysis of irrigation investments in existing and new plantations of coconuts in mixed cropping system, also reported the economic viability of investment in irrigation.

A comparative study of irrigation at 66,100 and 133% of Eo along with basin irrigation at 100% Eo and no irrigation with and without coconut leaf mulch was undertaken with WCT palms in Kerala, India (Dhanapal et al. 2000b). Water was applied during December to May through six emitters placed 0.75 m away from the bole of the palm. The nut yield obtained in drip (at all levels) or basin irrigation was not different, and they suggested adopting drip irrigation at 66% Eo. The quantity of water to be applied at this level will be 27 l palm^{-1} day^{-1} during December to February and 35 l palm^{-1} day^{-1} during March to May. The number of dripping points should be six for sandy soils and four for other soil types (Dhanapal et al. 1999). The rate of water application should be 2–3 l hour^{-1} emitter^{-1} (Fig. 7.1).

More emitters are required for the sandy soil because the horizontal spread is only about 50% of that of the laterite and red sandy loam soil and the wetted volume of active root is only 10.2% for four emitters. The wetted volume with 6 emitters is 15.1% (Dhanapal et al. 2000a). Dhanapal et al. (2003) studied the effect of drip irrigation in COD x WCT hybrid coconut palms in Kerala, India. For drip irrigation, water was applied at 2 l h^{-1} through 4 emitters placed 1 m away from the bole at equidistance with the help of 4 mm LDPE micro tubes, while water was applied in basins of 1.8 m radius under basin method of irrigation. The annual leaf production and leaf nutrient status improved due to irrigation. It was found that drip irrigation equal to 66% Eo was economically efficient with 34% water saving. They recom-

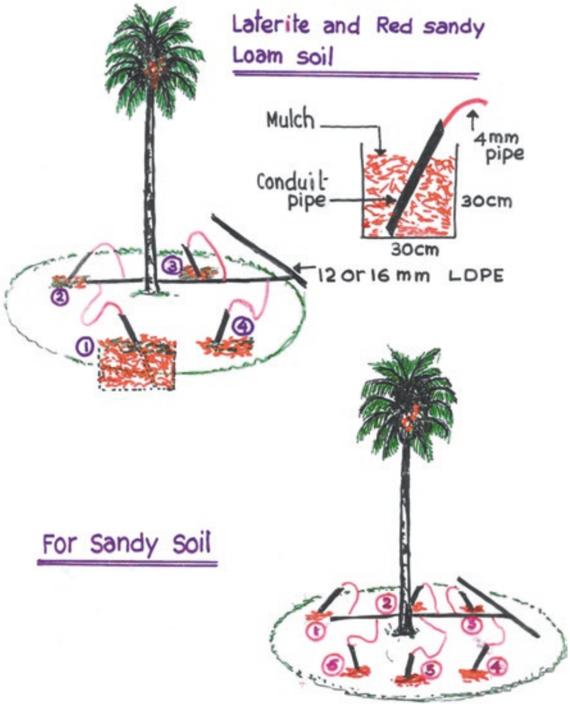


Fig. 7.1 Drip irrigation layout in the coconut basin. (Dhanapal et al. 1999)

mended, under Northern Kerala condition, to irrigate coconut palms through drip method at 27 l water palm^{-1} day^{-1} during December–January and 32 l water palm^{-1} day^{-1} during February–May. Similar results were reported in the case of WCT palms also (Dhanapal et al. 2004).

Factors which generally differentiate the soil water regime for drip irrigation from other irrigation systems are as follows: (i) the flow regime is two- or three-dimensional rather than vertical, (ii) water is added at high frequency and (iii) soil water is maintained within a relatively narrow range. A minimum of 15–20% of the active root zone should be wetted to absorb the water required by the palms. As the effective root zone of coconut palm is confined to 0.75–1.25 m from the bole, it is recommended to place the emitter or micro tubes 1 m away from bole. The quantity of water applied influenced the vertical and horizontal movement of water as well as the volume of root zone wetted in the coconut palm basin. The soil moisture content in various soil layers also was directly proportional to the rate of water application (Dhanapal et al. 1995). The per cent volume of active root zone wetted was 13.6 and 18.2, respectively, in surface and subsurface placement of emitters. The subsurface placement of emitters covered 35% more volume of the basin and maintained higher moisture than surface placed emitters. Thus, evaporation loss can be prevented by allowing water to drip at 30 cm depth by making a pit of 30 cm^3. A conduit pipe of 40 cm may be placed diagonally and the water allowed dripping in that pipe. The pit can be filled with locally available mulch or coir pith. Considering the yield ha^{-1}, cost/benefit ratio and water saving, drip irrigation with 30 l water $palm^{-1}day^{-1}$ during October to January and with 40 l water $palm^{-1}$ day^{-1} during February to May with four drippers placed at distance of 1 m away from the bole was recommended by Nagwekar et al. (2006) for WCT palms grown in sandy soil in Konkan region of India. The productive and economic advantages of drip systems, designed for areas with limited water supply compared to standard drip systems designed for full irrigation to meet potential evapotranspiration in Kerala, have been described by Keller et al. (1992).

7.5.4.3 Irrigation with Saline Water

Pomier and Brunin (1974) in Côte d'Ivoire studied the effect of irrigation with water having salinity (brackish water) equal to half the seawater (ECw = 23 dS m^{-1}) in coconut grown in soil with predominance of coarse sand. No damage was noticed on the palms, and the yield of palms under brackish water irrigation increased by 30%. Nagarajan et al. (1975) used seawater, fresh water and their mixtures in the ratios of 2.5:1 and 1:2.5 for irrigating coconut palms grown in sandy loam soil during summer months (December–May) by pot watering at 45 l of water $palm^{-1}$ $irrigation^{-1}$ twice a week in shallow basins. The palms did not suffer salt injury even though saline water was used for summer irrigation for more than a decade. Although salinity build-up in the soil as a result of these irrigations was much pronounced, highly permeable nature of the soil with low water table, leaching effect of rains (annually 3500 mm) and high salt-tolerant nature of the palms appear to be the favourable factors offsetting injurious effect, if any, of salinity on the palms.

A study on 1-year-old seedlings planted in sandy soil in Maharashtra, India, and irrigated with seawater, seawater + fresh water and fresh water indicated the adverse effect of undiluted seawater on the survival, growth and tertiary root production of seedlings (Patil et al. 1998). Higher levels of salinity had adverse effect on the growth of two coconut cultivars, Nigerian Dwarf Green (NGD) and Nigerian Red Dwarf (NRD) (Amalu 1998). For all parameters, chloride salinity was the most deleterious to growth followed by sulphate. Lower salinities (<4 mmho cm^{-1}) enhanced growth of seedlings, whereas higher concentrations (>12 mmho cm^{-1}) reduced dry matter production up to 50%.

The quality of tender nuts in relation to salinity of irrigation water was studied by Ferreira Neto et al. (2002). The increase in salinity of irrigation water (from 0.1, 5.0, 10.0 and 15.0 dSm^{-1}) increased the total soluble solids (° Brix) and the electrical conductivity of coconut water, especially when irrigated with water EC 15 dS m^{-1}. Increasing the salinity of irrigation water, besides reducing the weight and volume of coconut water, impaired the shape (appearance) of the nut. The chloride and potassium ions were found to be present in higher proportions. It was concluded that irrigating with water up to 10 dS m^{-1} can satisfactorily produce tender nut for marketing.

7.5.5 Fertigation

Fertigation is an efficient method of fertilizer application through drip irrigation system. Drip fertigation increases the fertilizer use efficiency, saves fertilizer cost, reduces labour requirement and supplies nutrients according to the crop demand besides helping in application of fertilizers exactly and uniformly to the wetted root zone (Dhanapal et al. 2005). Water soluble fertilizers like urea, diammonium phosphate (DAP) and muriate of potash (MOP) can be combined and supplied through drip irrigation. The other possibility is to use liquid fertilizers which are highly soluble and therefore do not cause any interference or clogging though it involves high cost. Through this method, fertilizers can be applied in six equal splits from December to May at monthly intervals in areas such as in Kerala.

Miguel et al. (2011) evaluated the effect of various doses of N (urea) and K_2O (potassium chloride) under fertigation in development and the production of Anão Verde coconut palm in Brazil. The number of leaves, canopy diameter, plant height and other parameters were improved with 2910 g $palm^{-1}$ $year^{-1}$ of K_2O and 2353 g $palm^{-1}$ $year^{-1}$ of N producing the highest production in sixth year of the crop. However, during the seventh year, the dose of 1540 and 1539 g $palm^{-1}$ $year^{-1}$ of K_2O and N, respectively, promoted maximum production. Though in the east coast region of Tamil Nadu, India, 100% of recommended dose of fertilizers (RDF) (0.56: 0.32: 1.20 kg N, P_2O_5, K_2O $palm^{-1}$ $year^{-1}$) was the best for obtaining higher values of yield attributes and nut yield, in addition to effective build-up of soil available NPK as well as economic viability. Thiruvarassan et al. (2016) suggested that the fertilizer application through micro-irrigation may be restricted to 75% of RDF (0. 42: 0.24: 0.90 kg) for obtaining sustainable coconut yields. Similar results were obtained by Basavaraju et al. (2014) in Karnataka, India, indicating the possibility of saving 25% of recommended NPK by adopting fertigation.

For West Coast Tall coconut palms, application of 50% of the recommended dose of fertilizers (0.50:0.32:1.20 kg N, P_2O_5, K_2O $palm^{-1}$ $year^{-1}$) through drip fertigation was sufficient to produce yield equivalent of 100% of the RDF through soil application (Subramanian et al. 2012a) (Table 7.1). Fertigation resulted in increased availability of soil N, P and K, higher annual leaf production and higher photosynthetic activity and production of more female flowers. However, Khandekar et al. (2016) from Maharashtra reported that application of 100% recommended fertilizer through drip (1.0 kg N + 0.5 kg P_2 O_5 + 1.0 kg K_2O $palm^{-1}$) in eight splits from October to May and was found suitable to increase yield (113.78 nuts $palm^{-1}$) with maximum net returns (Rs.108,000 ha^{-1}) for 28-year-old West Coast Tall variety.

Fertigation with polythene mulching increased the productivity in coconut, besides ensuring higher efficiency of water, nutrients and profitability in coconut (Jayakumar et al. 2017). They used different doses of fertilizers (100, 80 and 60% of recommended dose of 0.50:0.32:1.20 kg of N, P_2O_5, K_2O $palm^{-1}$ $year^{-1}$) with and without polythene mulch (100 μm thickness) along with basin irrigation without mulch in Tamil Nadu, India. All the plant growth characters (plant height, canopy development, etc.) and yield attributes (spathe length, number of inflorescences,

Table 7.1 Coconut yield as influenced by fertigation ($palm^{-1}$ $year^{-1}$)

Treatments	Pre-treatment yield		10 years' mean data	
	No. of female flowers	Nut yield	No. of female flowers	Nut yield
No fertilizer	262	102	226	81
25% NPK (drip)	254	111	280	97
50% NPK (drip)	257	106	306	121
75% NPK (drip)	239	108	294	123
100% NPK (drip)	248	108	326	131
100% NPK (soil)	272	114	276	114

number of bunches $palm^{-1}$ $year^{-1}$) as well as number of nuts $bunch^{-1}$ were maximum with fertigation using 100% of the RDF with polythene mulching. The number of nuts was also the highest (292 nuts $palm^{-1}$ $year^{-1}$) in the same treatment. Besides, gradual reduction in weed population, superior water and nutrient use efficiency and high profitability were observed in all the polythene mulch combination treatments when compared with other treatments without mulch.

7.5.6 Weed Management

Coconut is generally planted at a wider spacing resulting in growth of a wide range of annual and perennial weed species. Such weeds compete with coconut for soil moisture and nutrients, thereby affecting the growth and yield of coconut as well as obstructing routine cultural practices. Hence, it is necessary to adopt appropriate weed control measures in coconut plantations.

A variety of weed control methods are available, but Abad (1980) reported that hand weeding is the most common method of weed control in coconut gardens. However, if the area is too large and labour is costly, chemical control may become necessary. Use of kerosene or petrol-operated weed cutters is also common (Dhanapal et al. 2017). Gunathilake (1985) described the management practices including raising of cover crops, intercropping with shade-loving crops, cattle grazing or mulching with coconut fronds, husks or slashed weeds around palms in coconut plantations for weed management in Sri Lanka.

In new coconut plantations, weed control was carried out by establishing cover crops in furrows and spraying with Paracol (paraquat + diuron) at 1.2 kg or diuron 2.4 kg and paraquat 0.55 kg $hectare^{-1}$ between the furrows (Abad 1980). In trials at the Davao Research Center of the Philippine Coconut Authority, winged bean (*Psophocarpus tetragonolobus* L.) was found to be a suitable cover crop in coconut plantations where it suppressed weeds and improved soil fertility (San Juan and Abad 1981). Sanico and Laguna (1989) also found that cover cropping with *P. phaseoloides* was the most effective method in controlling weeds. Rolling between coconut rows with a light-weight wooden roller at the time of cover crop sowing controlled *Imperata* in young coconut plantations (Bourgoing and Boutin 1987). The highest average yield year^{-1} was obtained with clean scraping of the soil surface with inter-cultivation in mature WCT coconuts over a period of 6 years in Kerala (Mathai 1979).

Senarathne et al. (2003) compared different weed management systems and their effects on yield of coconut plantations in Sri Lanka. Controlling weeds with glyphosate at 1.44 kg ai ha^{-1} resulted in a 25% increase in nut yield over the uncontrolled weed plots and was found to be the most effective and economical method of weed control. Senarathne and Gunathilake (2010) evaluated tractor slashing (3 times per year), cover cropping with *P. phaseoloides* and buffalo grazing (once a month) for weed management in mature coconut plantations in Sri Lanka. Though both the latter treatments could effectively reduce the weed biomass, the yield was the highest in the buffalo grazing plots, which also gave the highest BC ratio of 1.86. Later on Senarathne and Perera (2011) reported that cover cropping with *P. phaseoloides* and application of glyphosate at 1.44 kg ai ha^{-1} were very effective resulting in 20% and 23% increase in nut yield over the uncontrolled weed plots, respectively.

7.5.7 Leaf Pruning in Coconut

Coconut leaf pruning (CLP) involves the removal of coconut leaves in the lower whorls of canopy so as to allow adequate sunlight for the normal development and high yield of perennial and annual crops, grown along with coconut. According to Sampson (1923), 6–8 lower leaves of a coconut palm which have past their prime and are of little use to the palm can be removed.

Coconut palms of five age groups, viz. 5, 10, 20, 30 and over 50 years, were studied to determine the effect of leaf growth in relation to age and the relation between leaf size and bearing status of such palms by de Silva and Abeywardena (1970). Leaf growth parameters (leaf length, petiole length and total number of leaflets) of 10-year-old nonbearing coconut palms were more than those of bearing palms of the same age. Marar and Padmanabhan (1970) measured the effects of CLP for a period of 4 years and found that removing old coconut leaves from axils of which mature nuts had been harvested did not harm palm growth or productivity. On the other hand, where all opened leaves on one side of the palms were removed additionally, there was significant decline in average production (45.6 coconuts palm^{-1} year^{-1} compared to 68.6 nuts before treatment). Bailey et al. (1977) recorded significant decline in coconut yield due to increased premature fruit shedding following pruning treatments and concluded that defoliation above 40% has long-term negative effects on the health of palms.

No change in yield was noticed in 55-year-old WCT coconut palms, in which 3–10 of the lower leaves were removed during the 5-month dry season of each year (January to May) for a period of 5 years (Sudhakara et al. 1989). Magat et al. (1994) tried maintaining CLP for a longer period of time and got different results. Although there was once again no decrease in yield during the first year, trees retaining the

13 younger leaves showed a 29% loss in production of nuts in the second year followed by a further 20% reduction in the third year, i.e. a nearly 50% decline in nut production after 3 years. Treatments retaining the 18 youngest leaves caused no significant decline and even showed an improved yield in the third year. Thus, it was concluded that maintaining 18 functional leaves in the crown was sufficient to provide optimum yield in coconut.

According to Dauzat and Eroy (1997), a possible alternative to choosing a lower density for intercropping purposes can be the pruning of the coconuts. Their simulations showed that limiting the frond numbers to 18 in coconut stands at regular densities is quite effective to enhance the light transmission. Pruning seemed to be a very flexible and cost-effective means to modify the light competition in a coconut-based farming system. Aterrado and Abad (1998) pointed out that no changes in yield occurred within the first year of pruning. The effect of pruning was felt a year after implementation when yield for 95% pruning dropped to 54.4 nuts palm^{-1} year^{-1} compared to 25% and 50% prunings with 86.8 and 77.1 nuts palm^{-1} year^{-1}, respectively. Eroy et al. (2001) reported that CLP did not significantly affect the yield in the first year, but nut and copra yield tree^{-1} had been significantly reduced by 21% and 17%, respectively, after 2 years.

In areas with a distinct dry period of 3–6 months with a monthly rainfall of < 1000 mm, leaf pruning during nut harvest before the onset of dry season can minimize the adverse effects of drought on the fruit set (Anon 2000a). In cases where damages of pests occur on lower and older leaves (e.g. attack of *Opisina arenosella* Walker, the black-headed caterpillar), pruning of these leaves would serve as a mechanical control measure. CLP is not recommended for very tall coconut palms due to the excessive transmission of sunlight under coconut and the difficulty usually encountered in pruning tall palms (Anon 2000a).

Padrones et al. (2000) from the Philippines reported that higher number of leaves was produced under pruned coconuts than those under non-pruned coconuts. However, nut and copra production of bearing palms were not significantly affected by leaf pruning. From a 9-year study on coconut leaf pruning (CLP) in the Philippines, involving local tall Laguna variety (19–28 years old, 9 m × 9 m triangular planting) intercropped with selected annual food crops (corn, peanut and sweet potato), Magat et al. (2002) reported reduction in nut and copra yield palm^{-1} with CLP starting at leaf ranks (LR) 19 or 23 and onwards. However, 2.3–2.8% increase was noted in copra weight nut^{-1}. There was better growth and yield (34% and 45% increase, respectively) for sun-loving annual intercrops (corn and peanut) with CLP, whereas the yield was not affected in the case of shade-tolerant sweet potato. Consequently, CLP contributed to higher income, higher net returns and benefit/cost ratio (BCR), thus, offsetting any reduction in coconut yield due to CLP practice eventually achieving optimized total farm productivity and maximum farm profitability.

Canja et al. (2003) carried out pruning of coconut palm from leaf no.19 (maintaining 18 younger leaves in the crown) and found that the CLP did not affect the yield and nutrition of coconut palms. Though lower number of nuts and copra yield palm^{-1} were observed on palms with CLP, there was improvement in copra weight nut^{-1}.

From an 8-year experiment conducted at the Davao centre, the Philippines, Secretaria et al. (2003) reported 20–25% decline in the yield of palms pruned to retain 18 youngest leaves. Based on yield reduction coefficients, they have developed yield predicting models in areas with well-distributed rainfall for local tall and hybrid coconuts under coconut-based farming system at two pruning levels (retaining 19 and 23 leaves).

Rosenfeld (2009) reviewed the research work done on pruning on the health of palms including coconut. He summarized the following points relevant to coconut:

(a) Pruning increased the rate of production of new leaves, but size of new leaves decreased as a result of higher levels of pruning.
(b) Leaf nutrients were not affected much by leaf pruning in healthy palms, but in nutrient-deficient palms, the symptoms became worse.
(c) There were significant negative effects on nut production when fewer than 18 younger leaves were retained.

The studies taken up so far on leaf pruning in coconut indicate that pruning retaining 18 functional leaves on the crown is advisable.

7.5.8 Underplanting/Replanting in Coconut

Coconut palms commence full production at the age of 10–16 years which continues at an increasing rate between 30 and 40 years and thereafter starts to decline (Nelliat et al. 1974). The useful bearing life of tall varieties is estimated to be up to around the age of 60 years. The main factor that leads to low income in coconut production systems in most of the coconut producing countries is the declining productivity of coconut palms due to old age and senility (Mwinjaka et al. 1994; Aguilar and Benard 1993). Replacing such palms is necessary to ensure that production and profitability are maintained so that the future of the industry is safeguarded (Ollivier et al. 2001). Magat (1993) reported that 15% of the palms in the Philippines were senile by 1990 and cautioned that unless replanting measures were promptly taken, there would be a 2% decline per annum in coconut production.

Coconut farmers are generally reluctant to uproot a palm even when it attains senility and becomes less productive, mainly because coconut has a long juvenile phase and therefore, the benefit from coconut is derived after a long time. Replanting, which is the complete removal of old coconut palms before new seedlings are planted, is an agronomically superior method in replacing a senile coconut plantation. This results in early flowering, early bearing and development of uniform plantation compared to the underplanting system (Perera and Fernando 2002).

In the underplanting system, new seedlings are planted along with the old palms, which are removed in stages over a period of 5–6 years. Even though most of the coconut farmers are aware that replanting is superior to underplanting with respect to the performance of the new plantation, the underplanting system is still being practised by the farmers, because the continued income from the old palms is necessary till the underplanted ones start yielding especially in small holdings.

Ollivier et al. (2001) suggested, considering variety, residual density, productivity and condition of the palms as the factors to decide replanting. Farmers who would like to take up underplanting should decide when to replace their palms judiciously. In Tanzania, under very different conditions of low rainfall and sandy soil, Romney (1987) observed that competition of adult tall palms is likely to substantially reduce the performance of the young palms. Sometimes, the old palms tend to show yield improvement due to the care given to the newly planted seedlings, which leads to reluctance of farmers to remove the old palms which is detrimental to the growth of underplanted seedlings.

Pordesimo and Noble (1989), in the Philippines, recommended ‘strip replanting’ based on a simulation model. Perera and Fernando (2002) suggested that if the plantation is over 60 years and is producing less than 2400 nuts ha^{-1} $year^{-1}$, replanting could be undertaken. The factors such as the height of the old palms that makes harvesting difficult, existing number of vacancies and severity of damage due to drought or long-term negligence are also to be considered along with the age and yield in deciding when to replace old plantation effectively.

In Samoa, Opio (1987) suggested that the yields of mature local tall varieties are not economically viable beyond 40 years, unless they are intercropped with other cash crops. According to Mwinjaka et al. (1999), there is a recommendation to coconut growers in Tanzania to replant their coconut fields when the palms are 66 years old. The gradual replacement of existing coconut palms should be undertaken at planting densities of 15–17 m × 10 m. This density, if maintained, will allow for various intercropping systems to be established. As the tendency is to replace old tall palms with more precocious and higher yielding D x T hybrid varieties, the density should often be higher than in the original design.

In the Philippines, vegetative pith or ‘ubod’ of coconut is an edible food item, which finds use in many food preparations. A system or strategy of underplanting seedlings among adult stand of palms was developed to provide an alternative source of ‘ubod’, thus, preventing the indiscriminate cutting of existing productive coconut palms for the purpose (Anon 2000b). This system involves planting of seedlings in the interspaces of full-bearing coconut in a 3 m × 3 m triangular pattern in two rows about 2 m away from the row of coconut-bearing palms. The seedlings are planted in pits either with 1 seedling per pit (742 seedlings ha^{-1}) or 2 seedlings per pit at 60 cm apart (1484 seedlings ha^{-1}). The ‘ubod’ can be harvested at 3 years from field planting. This system can also be used in replanting old existing palms with some remaining young palms arranged in a 9 m × 9 m triangular planting distance. However, this technology cannot be applied to full-bearing palms with close planting (<8 m), and, therefore, it is limited to tall-bearing palms and not for dwarf varieties with close planting. Padrones et al. (2000) from the Philippines recommended underplanting two young coconuts in each pit taken at 3 m × 3 m distance between spaces of coconut-bearing palms, which according to them is more profitable.

7.6 Coconut-Based Farming System

Very often, the coconut farmers in many parts of the world find difficulties in sustaining their families' livelihoods from the income of coconut alone. One of the best options to overcome this problem is to effectively utilize the space available in coconut gardens for cultivation of other compatible crops. Such a system will also offer considerable scope for increasing productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. Production alternatives for intercropping in coconut plantations can take the form of a single intercrop, a mixture of crops or a crop/livestock combination which are compatible with each other and other environmental factors. One of the most common farming systems practised by coconut-growing traditional farmers is the coconut-based farming system (CBFS).

According to Aguilar and Benard (1993), CBFS is the integration of complementary enterprises in coconut farming (e.g. intercropping, livestock, processing integration linked with marketing) to increase productivity unit area^{-1}, increase employment opportunities and provide a buffer against low and fluctuating copra prices. An example of a working definition of CBFS was given by Magat (1999) as: 'a system or practice in coconut production in which the available farm resources like coconut trees, soil and water/rainfall, farm labour, agricultural inputs (seeds, livestock, fertilizers and other agro-chemicals), and farm tools are utilized to produce nuts, food and non-food agricultural produce from the farm, in a productive and profitable way'. In any CBFS, integrated crop management practices of the main as well as intercrops should be followed to achieve optimum productivity, profitability and sustainability of coconut palms and to maximize the total productivity and economic benefits of the system.

Research programmes in the 1960s and 1970s enabled the development of many coconut-based cropping systems to increase the productivity and income from unit area of plantations without decreasing coconut yield. According to Liyanage and Gunathilake (1998), CBFSs have been recognized as a strategy for optimizing the productivity and augmenting the economic viability of coconut lands, particularly in the wet and intermediate agroclimatic zones in Sri Lanka, which comprise of nearly 80% of the land occupied by coconut. The success of cropping system in coconut gardens greatly depends on the canopy architecture and rooting pattern of crops; extent of availability of sunlight in the plantation; selection of crops adaptable to local climatic and soil conditions; arrangement of crops in relation to air space and soil utilization; shade tolerance, growth pattern and duration of the crops planned to be cultivated; irrigation facilities available; sociocultural factors of the farmers; marketing facilities for the products; as well as economic competitiveness of the crops.

7.6.1 Amenability of Coconut Palm to Cropping Systems

Coconut palm utilizes the natural resources only to a very limited extent producing less than 10% of the potential for dry matter production in the tropics (Nelliat et al. 1974). Mialet-Serra et al. (2001a) are also of the opinion that in mature coconut plantations, significant quantities of light, water and nutrients may not be captured by the palms and therefore can be utilized by intercrops without reducing main crop yield.

7.6.1.1 Space Availability

In gardens, with monocropping as little as 25% of the land is only effectively used (Ontolan 1988; Darwis and Tarigans 1990; Magat 1990). Though the potential (maximum) annual biological productivity of a cropping system under optimum conditions (Loomis and Williams 1973) is to the extent of 280.5 tonnes $ha^{-1}$of dry matter (770 kg ha^{-1} day^{-1}), according to Magat (1990), for coconuts, even at high nut yields of 100 nuts $palm^{-1}$ and 200 nuts $palm^{-1}$, the annual productivity is only 18.70 tonnes ha^{-1} and 35.5 tonnes ha^{-1} of dry matter or 6.6 and 12.6%, respectively, of the potential biological productivity. Due to the unique morphological features (with a terminal crown of leaves, growing to a height of 20–30 m), the coconut palms may occupy less than 30–40% of the available air space between canopy and ground during the major part of their life span of 80–100 years (Bavappa 1975).

7.6.1.2 The Rooting Pattern of Coconut

Though under favourable conditions, as many as 4000–7000 roots are found in the middle-aged coconut palms (Menon and Pandalai 1960), about 74% of the roots produced by a palm under good management do not go beyond the 2 m lateral distance. IAEA (1975) reported the depth and distance for coconut root to be 0.6 m and 4.0 m, respectively, in the Philippines, whereas the corresponding figures were 0.6 m and 3.0 m in Sri Lanka. In Bali, Steel and Humphreys (1974) showed that palm roots were still very dense at 3 m from the trunk and that some laterals occurred. Studies using P isotopes (Anilkumar and Wahid 1988) confirmed that more than 80% of the root activity was confined to an area of 2 m radius around the palm and to the 25–60 cm depth of the soil. Thus, on surface area basis, the area occupied by the palm is 56.25 m^2 (7.5 × 7.5 m); and the area of active root zone is 12.57 m^2 (πr^2 where r = 2 m). Therefore, the fraction of total area effectively utilized by the palm is only 22.24%. Thus, in a pure stand of coconuts at normal planting density and management conditions, about 75% of the total area is not being effectively utilized to the fullest extent by coconut roots.

7.6.1.3 The Availability of Solar Radiation

The venation structure of the coconut crown and the orientation of leaves allow part of the incident solar radiation to pass through the canopy and fall on the ground. According to Nair and Balakrishnan (1976), Liyanage (1985) as well as Liyanage and Martin (1987), on an average some 56% of solar radiation is available for intercrops, although this will vary with age of the coconut stand and planting density. The diffused sunlight facilitates growing a number of shade-tolerant crops in the interspaces. The leaves in a coconut palm crown are not randomly distributed, but clumped around few widely spaced growing points. This non-random distribution will also lead to low extension coefficient of around 0.65 for photosynthetically active radiation (PAR). Light penetration through the canopy is influenced by age, spacing, soil fertility, varietal characteristics, leaf area and time of the day. The amount of light transmitted ranges from 5% in a 5–10-year-old D x T hybrid at a density of 650 palms ha^{-1} to about 90% in a 60–70-year-old plantation at a density of 120 palms ha^{-1} (Reynolds 1995). In CBFS, transmitted radiation especially the PAR regime is very important as it has a bearing on the behaviour and productivity of intercrops. Intercropping experiments under coconuts in the Philippines demonstrated that, in the absence of strong water deficit and with a proper fertilizer supply, the intercrop yields are more or less linearly related to the available PAR (Benard et al. 1996). Thus, optimizing CBFS can be achieved mainly by providing sufficient light for intercropping through the choice of coconut density.

The apparent coverage of ground by canopies of palms of various age groups varies (Nelliat et al. 1974). When the palms are about 8–10 years old, the percentage of sunlight transmitted is only 20, and this remains almost constant till about 25 years. Subsequently, the percentage of light transmission increases progressively, and the canopy coverage of ground decreases inversely. By the time the palms are 40 years old, the light transmission increases to about 50%. Based on the growth habit of the palm and the amount of light transmitted through its canopy, the life span of coconut palm could be divided into three distinct phases from the point of view of intercropping.

A. Up to about 8 years: Good transmission initially; decreasing with age; suitable for growing annuals/biennials
B. Eight to 25 years: Maximum ground coverage and low canopy; poor light availability; not suitable for multiple cropping
C. Above 25 years: Increasing trunk height; reduction in crown size, light transmission increasing with age; ideal for raising annual and/or perennial crops

Classification of some of the crops based on tolerance to sunlight/shade for intercropping is as in Table 7.2.

The major criteria for selection of component crops are:

(1) Shade tolerance of selected crops and amount of solar radiation in the coconut garden
(2) Differential rooting pattern to exploit different soil layers for moisture and nutrients

Table 7.2 Classification of crops based on tolerance to sunlight/shade for intercropping

Sl. no.	Parameter	Effect on production/remarks	Examples of suitable crops
1	Not tolerant to even slight shade	Drastic decline in yield even under slight shade. Cannot be grown successfully as intercrop	Paddy, bhendi, sweet potato, leguminous plants, groundnut
2	Not tolerant to shade	Yield declines with intensity of shade. Can be grown in border areas	Coleus, brinjal, tomato, chilli, dioscorea, Nendran banana
3	Tolerant to shade	Slight reduction in yield due to shade. Can be grown successfully when 50% sunlight is available	Colocasia, cassava, amorphophallus, banana varieties other than Nendran
4	Shade loving	Yield increases to some extent with increase in shade. More ideal as intercrop than sole crop	Ginger, turmeric, arrowroot, Kacholam

(3) Possibility of supplying biomass for recycling
(4) Lesser height than coconut and non-interference with cultural operations of the main crop
(5) Should not be alternate host for any pest or disease
(6) Lesser economic life span than coconut
(7) Adequate marketing and processing facility
(8) Suitability of climatic conditions, soil type, rainfall pattern and irrigation requirements of the crops intended for inclusion in the cropping system

Dauzat (1995) and Dauzat and Eroy (1997) modelled the architecture of the coconut palm and generated virtual coconut stands in which simulations of light transmission was carried out. Subsequently the percentage of light transmission through the coconut canopy depending on the geographical location of the site, the age of the coconut palms and the adopted planting design was calculated, and the most suitable plants for intercropping according to the light environment under coconut were recommended. It was found, by simulations, that the PAR transmission under coconuts at a given age is sensibly a linear function of the tree density, irrespective of their planting pattern. Therefore, it could be possible to adjust the palm density according to PAR requirement of intercrops. Because the light transmission is similar in triangular and square designs, the choice of a coconut planting design may be guided by practical considerations, e.g. ease in cultural practices like cross ploughing in square designs (Dauzat and Eroy 1997).

7.6.2 Relevance of Coconut-Based Farming Systems

The main relevance of CBFS includes the following: social and ecological benefits, conservation of natural resources, biodiversity conservation, supply of biomass and employment generation.

1. Social benefits: Social benefits relate to the food and nutritional functions of coconuts as well as various crops grown under the system. Growing of intercrops in coconut lands produces more food and agricultural products, ensuring food security of the people in rural and urban areas. At the same time, the practice generates jobs and livelihood, enhancing farm incomes and the purchasing power of people and thus alleviating poverty in farming communities (Magat 2004a).
2. Ecological benefits: Compared to the ecological conditions of the long-term monoculturing, those of lands under CBFS are more favourable and stable for intensive and sustainable agricultural production. This is mainly due to the more efficient utilization of various natural resources, higher biomass generation and recycling over a period of time.
3. Conservation of natural resources: The land cover minimizes the direct impact of rainfall and the separation of soil aggregates under coconut environment, which can control surface runoff and soil erosion by 70–90%, compared to bare soil or uncropped condition. An adequate ground cover can also increase rainwater infiltration and storage, eventually increasing water supply of the entire area. Because of the shade under coconut stand and full canopy coverage, evaporative demand is very much reduced, and intercropping allows a better retention of water in the soil for a longer period. The microclimate in the coconut garden maintains not only lower air temperatures (by 4–6 °C beneath the canopy) but also lower soil temperatures.
4. Biodiversity conservation: Due to the uniqueness in the growth pattern, coconut offers scope for accommodation of many crop species for inter/mixed cropping, which in turn helps plant genetic resources conservation and management. The CBFS favours diversity in the soil microflora as well.
5. Supply of biomass for recycling and soil fertility improvement: CBFS enables production of large quantities of biomass which could be effectively recycled and put back in to the system for soil fertility improvement.
6. Employment generation from farm diversification: Since various crops with different growth patterns and durations are included in the CBFS, their cultivation coupled with value addition provides opportunities for more employment generation. Besides, mixed farming also offers year-round employment to the farm family.

The main cropping systems adopted in coconut plantations are the following.

7.6.3 Coconut-Based Intercropping

Growing annuals/biennials in the interspaces of coconut is referred to as intercropping. A large variety of crops have been found suitable for growing under irrigated and rainfed conditions. Intercropping takes advantage of the nature of the coconut palm's canopy and rooting system (Reynolds 1988; Proud 2005). Apart from the advantages listed above, intercropping helps to reduce the dependence on coconut products (which often experience an unstable market) and ensures economic support during the long juvenile period of coconut.

Several reports and experimental research results are available on intercropping in coconut gardens from different parts of the world covering a number of crops. Many reviews of the experiments in India on intercropping in coconut are available (Nair 1976, 1977; Nair and Bavappa 1975; Nair and Varghese 1976; Nair et al. 1974; Nelliat et al. 1974; Nelliat and Krishnaji 1976; Gopalasundaram and Nelliat 1979a, b; Chattopadhyay et al. 1995; Srinivasa Reddy and Biddappa 2000). These reviews indicate that the practice extends to many of the cultivated crops. Notable among them are cereals, tuber crops, pulses, oilseeds, fruit crops, rhizome spices, ornamental and medicinal plants and fodder grass (Table 7.3). Coconut intercropping systems followed in Peninsular Malaysia and Sri Lanka were described by Denamany et al. (1979) and Liyanage et al. (1984), respectively. The ideas and considerations for coconut farm diversification are given by Scheewe (2003).

The details of coconut-based cropping systems adopted in the wet and wet intermediate zones of Sri Lanka, their constraints and prospects are given by Ranatunga et al. (1988). Godoy and Bennett (1991) presented an analysis of the profits of cultivating modern and traditional varieties of coconuts as a monocrop as well as intercrop, under ideal and average growing conditions, with good and average management. The results showed that intercropping generated more income than monocropping by smallholders in Indonesia.

Tropical tuber crops such as cassava, elephant foot yam, colocasia, Chinese potato, sweet potato, greater yam and lesser yam were found to be suitable intercrops in coconut gardens. The tuber crops partially meet the food requirements of a farm family and almost always find a place in the homestead gardens of Kerala (Varghese et al. 1978b). In an intercropping trial of coconut with tuber crops at ICAR-CPCRI, Kasaragod, India, there was a general reduction in the yield of coconut when the intercrop alone was manured, but no such reduction was noticed when both the intercrop and the main crop were manured (Varghese et al. 1978b). Intercropping of tuber crops, elephant foot yam and yams resulted in increased yield of root (wilt) disease-affected coconut gardens. The cost/benefit analysis showed that coconut+tapioca combination gave the highest net return per rupee invested (Sethumadhava Menon and Ramakrishnan Nayar 1978). Ginger and turmeric are the important spice crops commonly intercropped in coconut gardens (Varghese et al. 1978b; Hegde et al. 1990). Experiments at Kasaragod, India, have indicated the suitability of vegetables like snake gourd, bottle gourd, brinjal, coccinia and bitter gourd as compatible crops with coconut (Hegde et al. 1993). Intercropping with vegetables helped to generate additional employment to the tune of 215 to 365 man-days ha^{-1} $year^{-1}$. Among the different sequences tried, snake gourd-ridge gourd-amaranthus were the most remunerative (Rs. 22,217 ha^{-1} $year^{-1}$) followed by amaranths-bottle gourd-brinjal (Rs. 20,920). Intercropping of fodder grass, vegetable crops (amaranthus, pumpkin and ash gourd) and fruit crops (banana and pineapple) could be successfully taken up in coconut gardens under coastal sandy soil by adopting appropriate soil moisture conservation measures, viz. husk and coir pith application in the planting zone (Subramanian et al. 2009).

Table 7.3 Common intercrops grown in coconut gardens in India

Crops	References
1. Fruit crops	
Banana (*Musa* sp. different varieties), Pineapple (*Ananas comosus*),Papaya (*Carica papaya*), Guava (*Psidium guajava*),Lemon (*Citrus* sp.)	Nelliat et al. (1974), Nair (1977), Gopalasundaram and Nelliat (1979b), Gopalasundaram et al. (1993), Maheswarappa et al. (2003), Subramanian et al. (2009), Athmanathan et al. (2000), and Girijadevi et al. (2013)
2. Fodder crops	
Hybrid Bajra Napier, Guinea grass, Fodder cowpea, S*tylosanthes gracilis*	Ramakrishnan Nayar and Sahasranaman (1978), Jacob Mathew and Mohamed Shaffee (1979), Sahasranaman et al. (1983), Maheswarappa and Hegde (1995), CPCRI (2004), and Subramanian et al. (2007)
3. Medicinal and aromatic crops	
Chittadalodakam (*Adhatoda beddomei*), Karimkurinji (*Nilgirianthus ciliatus),* Nagadanthi (*Baliospermum montanum),* Vetiver (*Vetiveria zizanioides)*,Indian long pepper (*Piper longum*),Noni (*Morinda citrifolia*),Arrow root (*Maranta arundinacea*), Galangal (*Kaempferia galanga*),Patchouli (*Pogostemon patchouli*)	Nair et al. (1991), Rajagopalan et al. (1992), Viswanathan et al. (1992, 1993), Lalitha Bai et al. 1996), Maheswarappa and Nanjappa (2000), Maheswarappa et al. (2000, 2008), Srinivasa Reddy and Arunachalam (2002), Suneetha and Chandrakanth (2003), CPCRI (2003, 2008), Ghosh et al. (2007a), Mohandas (2011), Ravi Bhat and Krishnakumar (2011), Bari and Rahim (2012), Nagwekar et al. (2013), Khandeker et al. (2014), Thiruvarassan and Maheswarappa (2014), and Nath et al. (2015)
4. Flowering crops	
Heliconia sp., *Anthurium* sp., *Jasminum* sp.	CPCRI (2003) Arunachalam and Reddy (2007), and Nihad and Krishnakumar (2015)
5. Tree crops	
Acacia mangium, *Acacia auriculiformis*, *Casuarina equisetifolia*,*Ailanthus* sp., *Tectona grandis*, *Tamarindus indica*, *Erythrina indica*	CPCRI (1989)
6. Spices/tree spices	
Ginger (*Zingiber officinale*),Turmeric (*Curcuma longa*),Black pepper (*Piper nigrum*), Nutmeg (*Myristica fragrans*),Cinnamon (*Cinnamomum verum*),Clove (*Syzygium aromaticum*) Vanilla (*Vanilla planifolia*)	Nelliat et al. (1974), Nair (1977), CPCRI (1984, 2009), Jayachandran et al. (1991, 1998), Sharma et al. (1996), Manjunath et al. (1998), Srinivasa Reddy et al. (2000), Maheswarappa and Anithakumari (2002), Nagwekar et al. (2002), and Maheswarappa et al. (2003, 2012)
7. Beverages	
Cocoa (*Theobroma cacao*),Coffee (*Coffea arabica/C. robusta*)	Nelliat et al. (1974), Nair et al. (1975), Nair (1977), Abdul Khader et al. (1984), Bavappa et al. (1986), and Elain Apshara (2013)

(continued)

Table 7.3 (continued)

Crops	References
8. Other crops	
Mulberry (*Morus* sp.),Ramie (*Boehmeria nivea*)	Shanthamallaiah et al. (1982a, b), CPCRI (2002), and Manjunath et al. (2010)
9. Millets	
Varagu (*Panicum scrobiculatum*),Finger millet (*Eleusine coracana*)	Nambiar (1978)
10. Pulses	
Horse gram (*Macrotyloma uniflorum*), Cowpea (*Vigna unguiculata*),Bengal gram (*Cicer arietinum*),Soybean (*Glycine max*)	CPCRI (1975), Shanthamallaiah et al. (1982b), Joseph (1992), Lourduraj et al. (1992), Hegde and Yusuf (1993), and Jayaraman and Subramanian (1994)
11. Oilseed crops	
Groundnut (*Arachis hypogea*)	Sahasranaman (1964), Kannan and Nambiar (1976), and Leela and Bhaskaran (1978)
12. Tuber crops	
Elephant foot yam (*Amorphophallus paeoniifolius*) Cassava (*Manihot esculenta*) Sweet potato (*Ipomoea batatas*) Colocasia (*Colocasia esculenta*) White yam (*Dioscorea rotundata*)	Kannan and Nambiar (1976) Menon and Nayar (1978) Varghese et al. (1978a) Suja et al. (2003a, b, 2004a, b) Girijadevi et al. (2013) Krishnakumar et al. (2013)
13. Vegetables	
Chilli, French bean, dolichos bean, tomato, knolkhol, capsicum, brinjal, snake gourd, bottle gourd, amaranthus, coccinia, bitter gourd, ridge gourd, cucumber, cluster beans, etc.	Sahasranaman (1961), Shanthamalliah et al. (1982a), George and Nair (1987), Rethinam (1989), Patil et al. (1992), Hegde et al. (1993), Nagwekar et al. (1997), and Manjunath et al. (1998)

Intercropping trials at ICAR-CPCRI Kasaragod with ornamental, medicinal and aromatic crops in coconut gardens revealed that *Heliconia*, anthurium, *Jasminum pubescens* and marigold under ornamental crops and long pepper and patchouli under medicinal crops were compatible as intercrops in coconut garden (CPCRI 2003). A medicinal plant *Plumbago rosea* L. (known as rosy-flowered leadwort) was successfully grown as intercrop in coconut gardens and the use of bio-resources such as neem cake and FYM in the ratio of 1:4 along with microbial inoculants was suggested to achieve the highest benefit/cost ratio (Nihad et al. 2010). Intercropping of flowering plant, *Heliconia stricta*, in root (wilt) disease-affected coconut gardens enabled to enhance the profitability from such gardens (Nihad et al. 2013).

Among the fruit crops, banana is a popular, stable and marketable long-term crop that could be planted between stands of coconut palms. To be a compatible and productive intercrop, banana suckers are to be planted 2 m away from the base of coconut palms. Banana can be intercropped in gardens when the coconut palms are 1–3 years old and from the 25th year. Generally, banana and coconut do not compete for soil resources, except when grown in dry zones. Magat (2004b) and

Secretaria and Magat (2006) from the Philippines had described the agro-management practices to be followed when banana and root crops are to be intercropped in coconut garden.

Ennin et al. (2009) reported replanting of coconut with lethal yellowing disease (LYD) tolerant MYD x VTT hybrid intercropped with banana and cassava with minimum fertilizer application. This system showed biological compatibility in that they did not affect the vegetative growth of young coconut and produced high cassava yield (mean of 35.3 tonnes ha^{-1}) and banana yield (mean of 2.9 tonnes ha^{-1}) giving high economic returns with a B/C ratio of 5 for cassava.

A study on the effect of cropping systems, residue management and tillage practices on organic carbon sequestration in clay loam soil in Kerala, India, revealed that among the different cropping systems, coconut + pineapple cropping system maintained the highest soil organic carbon (SOC) content of 1.30% at the end of 2 years, whereas the coconut + maize system maintained only 1.21% SOC. Surface mulching with crop residues could maintain SOC carbon up to 1.37%, but when the residues were incorporated to soil, the SOC status was only 1.1%. Among tillage practices, reduced till maintained 1.29% SOC, whereas the conventional tillage could maintain only 1.22% SOC after 2 years. Improvement in soil properties, like aggregate stability, porosity, bulk density and water-holding capacity, was observed with the maintenance of SOC which was reflected on yield and returns (Sudha and Annamma 2011).

Lamanda et al. (2008) used 3D architectural modelling approach for providing indicators for assessing above-ground competition for light and below-ground competition for space, in order to optimize intercropping in 6–60-year-old coconut holdings. Intercropping with shade-tolerant species was not limited by light transmission from the 35th year after coconut planting. However, at that stage of coconut tree development, the density of primary roots in the interrow limited intercrop development, especially for root and tuber crops. Tubers such as taro, yam, cassava and kava are therefore not recommended in this type of intercropping unless the number of coconut palms is reduced. This modelling approach could be used for recommending coconut planting patterns and densities, as well as indicating intercrop potential depending on their location in the most sunlit areas with minimum root competition.

7.6.4 Coconut-Based Mixed Cropping

Growing of perennial crops with adult coconut palms is referred to as mixed cropping. A number of perennials like cacao, clove, nutmeg, coffee, black pepper, mulberry, cinnamon, mango, sapota, papaya, cardamom and other crops are successfully grown with coconut.

Mixed cropping coconut with perennials is popular in large-scale plantations. Perennials are particularly suited for mixed cropping with coconut because once they reach maturity, they continue to provide a steady flow of income with limited maintenance requirements. This is also considered important under smallholder production systems where resources are limited. Coffee is a popular mixed crop under mature coconut stands. The shade from coconut palms provides optimum conditions for coffee's growth and productivity. The crop is best planted at 2 m away from the base of coconut palms in three rows at 3 m × 3 m triangular system under coconut grown at a spacing of 10 m × 10 m square or two rows at 3 m × 3 m in a triangular pattern under coconut at a spacing of 8 m × 8 m or 9 m × 9 m square. Canja and Magat (2006) described the agro-management practices to be adopted for coconut-coffee mixed cropping in the Philippines. In this system, application of fertilizers to coconut with or without coffee fertilization increased copra yield significantly, whereas application of fertilizers to coffee, without coconut fertilization, gave low yield suggesting that coconut could not benefit from the fertilizers applied to coffee. Margate et al. (1993) suggested the need to apply fertilizers separately to both the crops. Economic analysis revealed that fertilizer application to both coconut and coffee gave the highest net return followed by that for coffee alone.

The profitability of growing cacao as mixed crop in coconut has been established in field experiments conducted at two locations in Kerala, India (Nair et al. 1975; KAU 1979). According to Creencia (1979), coconut areas producing at least 50 nuts palm^{-1} year^{-1} may be intercropped with cacao. The productivity of coconut and net return from the system were significantly higher under mixed cropping with cacao both in double hedge and single hedge systems. The double hedge system was found superior at Pilicode (Kerala) in an experiment conducted in plantations where the coconut palms were cultivated at a wider spacing of 9 m × 9 m. In Kerala, India, coconut intercropped with double rows of cacao was more profitable than that intercropped in a single row (Nair 1979; Bastine et al. 1986).

Mixed cropping with Forestero variety of cacao in 16-year-old root (wilt) disease-affected West Coast Tall coconut palms in single and double hedge systems increased the coconut yield by 27–35% as compared to that of monocropping (Kamalakshy Amma et al. 1982). There was also a build-up in the soil nutrient status which was more pronounced at 4 m than at 1.5 m away from the base of palm, where cacao was planted. The status of nutrients was low in double hedge system, perhaps due to the effective utilization of nutrients and higher yields of crops per unit area. Evaluation of 9 elite clones of cacao in double row system of planting in the plantation of Laccadive Ordinary Tall coconut cultivar revealed that VTLCP-22 and VTLCP-1 involving crosses of NA-33 and II-67 x NC-29/66 performed best with high vigour and yield under coconut (Elain Apshara 2010).

The microclimate of coconut garden (planted at 7.5 m × 7.5 m) mix cropped with cacao and cinnamon (two rows of cacao or two rows of cinnamon planted in double hedge system between coconut rows) was studied by Balakrishnan et al. (1976), and they reported considerable reduction in the evaporation during the peak period (December to May) in the mixed cropped field compared to the open surface. The diurnal variations on relative humidity and vapour pressure in the microclimate of cacao and cinnamon were also relatively much less compared to those of microclimate of coconut.

Studies of coconut-based agroforestry system on the aerial development in cacao in monoculture and intercropped with coconut by Mialet-Serra (1998) in Vanuatu and Indonesia have shown that some architectural features of young cacao can be influenced by the amount of shading, from the coconut palms, leading to differences between monoculture and intercropped conditions. In East Java, Indonesia, Karmawati et al. (2010) found that the production of cacao under the shade of coconut palms was normal and stable, having almost similar productivity as the monoculture system. Such conditions could be achieved through spacing of coconut palms at 12.0 m × 8.0 m or the density at 104 palms ha^{-1} and cacao with spacing of 3.0 m × 2.0 m and 1152 trees ha^{-1}. Utomo (2013) studied the environmental performance of cacao production from monoculture system and agroforestry system in Indonesia. The land productivity ratio (LER) of cacao-coconut agroforestry was the highest (1.36), indicating the higher level of yield advantages from this system. It also had soil fertility advantages in terms of higher content of organic carbon, C:N ratio and soil organic matter, which stimulated growth and activity of two beneficial soil microbe groups (bacteria and fungi) that exist in the cacao-coconut system. Such a system will also have the least impact on global warming, acidification and eutrophication.

Unlike in some other cacao-growing countries, cacao is not grown under the shade of coconut in Ghana. Osei-Bonsu et al. (2002) compared the merits of four cacao-coconut cropping systems with the traditional cultivation of cacao under *Gliricidia sepium* shade. Growth of cacao seedlings was not affected when grown under coconut, whereas growth and yield were considerably affected when mix cropped with *G. sepium.* Seven years' mean dry bean yield of cacao and profitability was the highest (1.23 tonnes ha^{-1}) when cacao was spaced at 2.5 m (1739 ha^{-1}) under a spacing of coconuts at 9.8 m in the triangular system (105 palms ha^{-1}).

Large coconut areas on fertile alluvial clays along the west coast of Peninsular Malaysia have been underplanted with cacao. The favourable price of cocoa beans, the unstable copra prices and the suitability of coconut shade have accounted for the success of this cropping system.

Mixed cropping of cacao under older stands of coconuts resulted in greatly improved economic returns in Malaysia (Ramadasan et al. 1978). Magat and Secretaria (2007) described the agro-management practices to be adopted for coconut-cacao mixed cropping in the Philippines and by Daswir and Dja'far (1988); Abbas and Dja'far (1989) in North Sumatra, Indonesia. Fagon and Topper (1988) found in Jamaica that close planting of cacao under coconuts was beneficial than wider spacing to get higher cocoa yield. Dootson et al. (1987) studied the effect of underplanting modern Upper Amazon cacao in 15-year-old Thai Tall coconuts and reported increase in economic returns once the cacao came into bearing. According to Mathes (1986), the relative return to a cacao-coconut mixed cropping was the second highest compared to coconut alone, coconut-coffee (*Coffea robusta*) and coconut – black pepper cropping systems.

In the study conducted in coconut stands at different densities at the Davao Research Center of the Philippines Coconut Authority, Dauzat and Eroy (1997) computed three-dimensional numerical mock-ups of coconut palms. Mialet-Serra et al. (2001b), using plant architectural models for estimation of radiation transfer in a coconut-based agroforestry system in Côte d' Ivoire, tried to validate the model computed by Dauzat and Eroy (1997), which predicted the yield of understorey corn and mung bean intercrops as a function of estimated transmitted PAR in several planting patterns and densities of coconut. They obtained good agreement between the estimated PAR through a coconut canopy and field measurements at several sites for several varieties with various planting patterns and densities. Thus, by using 3D numerical mock-ups of coconut linked to the radiation calculation modules, the distribution of transmitted radiation reaching the soil under a coconut stand could be estimated accurately for various planting patterns. However, their method has some limitations for large-scale adoption.

Nelliat et al. (1979) and Srinivasa Reddy and Thomas (2001) have reported the beneficial effect of growing cacao, black pepper, clove, nutmeg and cinnamon as mixed crops in coconut plantations (CPCRI 1975, 1979). Panniyur-1 variety of black pepper yielded 2 kg of dried berries vine^{-1}, and the maximum yield was 5 kg vine^{-1} (Anon 1977). Experiments conducted under Goa (India) conditions revealed that black pepper grows satisfactorily as mixed crop in coconut gardens and the plants started yielding from the third year onwards. The average yield obtained from a 1 hectare coconut garden was 0.76 t and 0.44 t of dry black pepper from Panniyur-1 and Karimunda varieties, respectively (Mathew et al. 1993b).

Shanthamallaiah et al. (1982b) reported that mulberry as a mixed crop increased the yield of coconut by 920 nuts and net income by Rs. 7379 ha^{-1} and doubled the employment potential. The profitability of growing perennial spice crops such as clove, nutmeg and cinnamon has been reported (Nelliat et al. 1979; Srinivasa Reddy et al. 1998b, 2000). Experiments at ICAR-CPCRI, Kasaragod, on mixed cropping with black pepper, clove, nutmeg and cacao indicated highest net returns with coconut + nutmeg cropping system (Rs. 94,300 ha^{-1}) followed by that in coconut + clove (Rs. 46,800 ha^{-1}) compared to coconut + black pepper (Rs. 26,200 ha^{-1}) and coconut + cacao (Rs. 31,400 ha^{-1}). The net return under coconut alone was only Rs. 22,300 ha^{-1} (Nair et al. 1991). Mixed cropping with spice crops such as cinnamon, clove, nutmeg, black pepper, garcinia and allspice was beneficial in Ratnagiri, Maharashtra (India), to increase the coconut yield (Patil et al. 1991).

Vanilla (*Vanilla planifolia*), a climbing orchid and a shade-loving spice crop, has been found to be a suitable mixed crop in coconut gardens. Growing vanilla in coconut gardens with the application of cow dung slurry (6 tonnes ha^{-1} in two splits or vermicompost 5 kg plant^{-1} year^{-1} in two splits along with biofertilizers of phosphate-solubilizing *Bacillus* sp. and nitrogen-fixing *Azospirillum* sp. at 25 g plant^{-1} year^{-1}) resulted in higher fresh bean yield and improvement of microbial properties in rhizosphere. There was 53% increase in coconut yield in vanilla intercropped plots compared to the pre-experimental yield (Maheswarappa et al. 2016). However, vanilla is not a preferred crop now due to very low price of the vanilla beans.

Coconut canopy was found to provide adequate shade for shade-loving cardamom (*Elettaria cardamomum*) in the mixed cropping system in Karnataka, India, which increased overall profits from the coconut gardens and the net return from the system was 2.5 times greater than from monocropping (Korikanthimath et al. 2000a, b).

Maheswarappa et al. (2008) evaluated the performance of different medicinal plants such as Orila (*Desmodium gangeticum*), Moovila (*Pseudarthria viscida*) and Coleus (*Coleus aromaticus*) (herbs of 8 months duration), Chittadalodakam (*Adhatoda beddomei*), Karimkurinji (*Nilgirianthus ciliatus*) and Nagadanthi (*Baliospermum montanum*) (shrubs of 18 months duration) as inter/mixed crops in a 30-year-old WCT coconut garden spaced at 7.5 m × 7.5 m at ICAR-CPCRI, Kasaragod, India. Among the annuals, Orila recorded the highest net return (Rs. 12,929 ha^{-1}), while among the biennials, the highest net return obtained was with Karimkurinji (Rs.1,93,049 ha^{-1}). Mohandas (2011) reported the suitability of sitharathai (*Alpinia galanga*), chotrukuthali (*Aloe vera*) and tulasi (*Ocimum sanctum*) as medicinal plants and lemon grass (*Cymbopogon flexuosus*) and patchouli (*Pogostemon patchouli*) as aromatic plants for intercropping in a 36-year-old East Coast Tall coconut garden at the Coconut Research Station, Veppankulam, Tamil Nadu, India.

Mensah and Ofosu-Budu (2012) evaluated coconut-citrus mixed cropping systems in the context of lethal yellowing disease of coconut in Ghana and found that MYD x VTT coconut hybrid planted at 9.5 m triangular offered optimal spacing for citrus mixed cropping at the convergence point of two diagonal lines linked with 4 adjacent coconut palms. The mixed cropping system did not hinder the optimal growth and yield of coconut or citrus, whereas it enabled a more efficient use of land and generated higher productivity by fitting more trees per unit area of land as compared with sole cropping. Though the cost-benefit ratio of the intercropping came next to sole coconut planting, intercropping provided 26% of fruit income as insurance against lethal yellowing disease.

From multidimensional analysis of coconut-based mixed farming systems adopted by farmers, Thamban et al. (2006) reported coconut + areca nut + black pepper + banana was the most commonly adopted model of CBFS followed by coconut + areca nut + black pepper system. The degree of crop intensification varied widely across the farms, and the economic analysis of various CBFS models indicated that they are technically feasible and economically viable. The level of profitability increased with increase in the number of the component crops.

7.6.5 Coconut-Based Agroforestry System

Coconut-based agroforestry systems hold promise as a sustainable land-use activity in areas where food and nutritional security is of concern and availability of land for expansion of cultivation is limited. The task in coconut farms is to diversify by integrating fruit trees and multipurpose trees. The numerous crop species in the homesteads serve the primary needs of the farmers' families. Apart from food, the small plots provide fuel, fodder, timber and cash.

An agroforestry experiment was conducted at ICAR-CPCRI, India, with different tree species during 1983 in an adult coconut garden. Data on coconut yield has shown that with high population of subabul, casuarina and eucalyptus, the coconut yield was adversely affected, whereas *Ailanthus* tree, though slow growing, appeared to be compatible with coconut and had not affected the yield of coconut (CPCRI 1989). Taffin et al. (1991) developed stable cropping systems combining coconut and N-fixing trees such as *Acacia mangium*, *A. auriculiformis* and *Casuarina equisetifolia. A. mangium* produced maximum biomass (457 kg ha^{-1}), while A. *auriculiformis* provided the highest volume of harvested wood (49 m^3 ha^{-1}). Liyanage et al. (1993a) studied growth performance and biomass yield of four nitrogen-fixing trees (NFT) (viz. *A. auriculiformis*, *Calliandra calothyrsus*, *G. sepium* and *L. leucocephala*) and their effect on coconut yield by planting them in double rows of 2 m × 1 m in the avenues of coconut. Due to the compatibility between coconut and NFT's, nut yield of coconut has also been increased by 15–26% in different NFT plantings. Coconut-based agroforestry systems, particularly with NFTs, offer much scope for reducing the use of fertilizer inputs through biological N-fixation, recycling of nutrients and by adding organic matter (Gunathilake 2011). Among them, *G. sepium* has been the best species. The coconut-NFT tree-based integrated system helps to minimize additional input of fertilizers in coconut plantations, thus saving on fertilizer cost (Tennakoon 2011).

Peiris et al. (2003) evaluated 26 agroforestry models developed and established in farmers' fields by Coconut Research Institute of Sri Lanka for studying their economic feasibility and biological productivity and found that all economic indicators including net present value (NPV) of agroforestry models were higher than the monocrop indicating their economic sustainability in the long run. The study of Bullecer et al. (2006) from the Philippines indicated that agroforestry systems could be improved by using more strategic plant combinations, plant densities and planting patterns for the different life stages (and related growth patterns) of the coconut palms. According to them planting of fast-growing and tall timber trees under coconut is not advisable, and more than 30% shading adversely affects its growth. Only shallow-rooted and shade-tolerant intercrops should be planted within a 3 m radius around the coconut trees. They found that planting fast-growing and timber trees under coconut such as *Leucaena*, *mahogany* and *gmelina* can adversely affect nut production and, hence, not recommendable. While environmental protection is afforded, economic benefits from coconut are reduced which could make the scheme less acceptable to farmers. They suggested more in-depth studies before potential best coconut-based agroforestry systems can be identified and extrapolated to other areas. The financial analysis conducted in Davao City by Secretaria and Magat (2004a, b) showed that the farming system combining coconut and *gmelina* is profitable even though coconut yield is reduced to a certain extent.

7.6.6 High-Density Multispecies Cropping System

High-density multispecies cropping system (HDMCS) or multistoried cropping system involves growing coconut and a combination of annual and perennial crops of different heights, rooting characteristics and canopy patterns in the same garden (between coconuts) so as to maximize utilization of solar radiation, nutrients and moisture (Nelliat et al. 1974; Bavappa et al. 1986; FSSRI-PCA 1984). This system requires more management skills, labour and other inputs than most other systems (Ohler 1992). Diversifying the farming system by intercropping cash crops, such as cacao, coffee, banana, pineapple, etc., and changing to multistoried cropping systems can generate much higher returns (Proud 2005).

Crops having varying canopy heights are selected in this intensive cropping system with the objective of greater utilization of solar energy and soil resources. The most profitable multistoried cropping system with coconut as main crop (1 ha) was established at ICAR-CPCRI, Kasaragod, India, with black pepper trained on coconut, 350–600 cacao seedlings planted between rows of coconut and 3500 pineapple suckers planted between rows of coconut and cacao. The output from the system included 17,000 coconuts, 300 kg dried beans of cacao, 60 kg dry pepper and 4 tonnes of pineapple in the single hedge system ha^{-1} $year^{-1}$ (Nelliat et al. 1974, 1979). Based on the feasibility, marketability and economic viability, among the eight different cropping models evaluated by Thiruvarassan et al. (2014) in a 25-year-old East Coast Tall (ECT) coconut garden, the one with coconut + black pepper + banana + elephant foot yam recorded the highest B/C ratio (2.16) and net income (Rs. 57,577 ha^{-1}) in the east coast region of Tamil Nadu, India.

A multistoried cropping experiment at Lampung indicated that the highest income was obtained with cropping system of cacao + cinnamon (*Cinnamomum* sp.) + black pepper + pineapple, followed by banana + maize and kapok (*Ceiba pentandra*) + cacao (Dwiwarni et al. 1987). Margate and Magat (1983) reported that planting black pepper (on the base of coconut palms) + pineapple (1 m × 1 m) + dwarf papaya (3 m × 3 m triangular)/Forastero cacao (3 m in a row), together with coconuts (planted at 9 m × 9 m square system) in a multistoried cropping system, increased nut yield and copra production $palm^{-1}$ as well as the total profitability of all the crops planted in the same area. The income generated from the intercropping system was more than double that of monocropping. However, Cabangbang et al. (1991) and De Luna (2008) reported that net incomes are lower in farms with more intercrops due to substantial additional labour costs incurred when integrating more intercrops in coconut farms. Income from the four-crop combination involving coconut + coffee + black pepper + *lanzones* is half that from the two-crop combination of coconut + coffee (Cabangbang et al. 1991). Thus, while diversification or intercropping is admittedly one good strategy to increase farmers' income, identifying the right combinations of intercrops is crucial considering the additional expenditure requirements of each intercrop.

Growing a large number of crop species in unit area of coconut plantation at high plant densities is practised to achieve maximum resource use efficiency and to meet the diverse needs of the farmer. A high-density multispecies cropping system model with many compatible annual/perennial crops (with 17 species) at higher plant density (total of 14,976 planting points ha^{-1} of coconut plantation) was established at Central Plantation Crops Research Institute, Kasaragod, India, during 1983 (Bavappa et al. 1986). A gross margin of Rs. 92,230 ha^{-1} was realized in 1996–1997 compared to Rs. 1750 ha^{-1} during 1983–1984 (Sairam et al. 1999). As the perennial crops grew and utilized more and more space, the annual crops except banana were removed so that the system consisted of nutmeg, banana and pineapple in the coconut garden. The coconut yield increased by 176% as compared to the pre-experimental yield as a response to the adoption of high-density cropping system and irrigation provided to coconut and companion crops.

This experiment was subsequently maintained with different levels of recommended dose of fertilizers. The mean productivity of crops revealed that the yields declined with reduction of fertilizers below one-third of recommended dose in the system. The coconut yield did not vary much between one-third, two-third and full dose of recommended fertilizers (147 to 157 nuts palm^{-1} year^{-1}). The component crops performed better under two-third and full dose of fertilizers in the system. Hence, only two-third level of recommended fertilizers was found necessary to sustain the yield of coconut and component crops at economically higher levels (Srinivasa Reddy et al. 2000). The biomass availability varied from 17 tonnes ha^{-1} in control to 22.58 tonnes ha^{-1} in full recommended fertilizer treatment. Coconut yield and economics of the system indicated the possibility of maintaining the system with one-third level of fertilizers complemented with biomass recycling (CPCRI 2002). In Assam, India, adoption of HDMSCS involving coconut + black pepper + banana + Assam lemon + pineapple + ginger and coconut + betel vine+ banana + Assam lemon + turmeric + colocasia had resulted in a nut yield increase of 110 and 83%, respectively, over pre-experimental nut yield (Chowdhury and Deka 1997).

In Sri Lanka, studies on canopy architecture in a multispecies cropping system involving 13 fruit crops by Jamaluddeen and Jacob (1983) indicated that the percentage increase in canopy diameter between 24 and 33 months after planting was greatest with coffee (59), followed by mango (51), coconut and jackfruit (both 40). Studies in the Mid Country Research Station, Sri Lanka, indicated the agronomic and economic potential with cash crops such as black pepper, coffee and clove and food crops such as banana and lime (Premaratne and de Silva 1991). This system was found to be financially viable in improving the income levels of upland farmers. High capital cost for establishment of the system is the only disadvantage of the system.

The results of various studies conducted in Kerala, India, indicated increased coconut yield due to introduction of HDMSCS compared to the monocropping of coconut (Maheswarappa et al. 2003, 2005; Maheswarappa 2008; Krishnakumar and Maheswarappa 2010). The increase in yield of coconut palms from the initial level of 30 nuts to 75.8 nuts palm^{-1} was reported in root (wilt) disease-affected area through adoption of HDMSCS (Maheswarappa et al. 2003). The crops like banana, pineapple, black pepper, nutmeg and tuber crops performed very well and provided additional yield and income. The higher B/C ratio of 2.28 and higher positive net present worth (Rs.1,80,106 ha^{-1}) indicated that HDMSCS is economically viable in root (wilt)-affected area. Improvement in properties like water-holding capacity, organic carbon as well as major and micronutrient status of the soil was observed due to adoption of integrated nutrient management practices and HDMSCS (Maheswarappa et al. 2005). The improvement in the yield of the palms was coupled with reduction in root (wilt) disease intensity indices due to reduction in yellowing of leaves. The percentage increase in average yield was 54.5, 52, 48.3 and 40.9, respectively, under apparent healthy, disease early, disease middle and disease advanced palms in comparison with pre-experimental yield. From the root (wilt) disease-affected gardens of Kerala, India, Krishnakumar et al. (2011) reported the economic advantage of HDMSCS over monocropping being 61% with a B/C ratio of 1.59 indicating that the coconut-based high-density cropping system is economically viable in root (wilt) disease-affected areas provided the disease is well managed by adopting integrated practices.

HDMSCS supplies large quantities of biomass for recycling and thus offers scope for reducing the need of inorganic fertilizers for coconut and component crops. Palaniswami et al. (2007) studied the possibility of reducing the quantity of inorganic fertilizer application to coconut and various component crops cultivated in HDMSCS in Kerala, India, and reported the mean yield of coconut to range from 127 nuts palm^{-1} under no fertilizer treatment to 147 nuts palm^{-1} with either 66 or 33% of recommended fertilizer dose (Table 7.4). The productivity of palms declined beyond 33% of the dosage. The yield of clove and black pepper was the highest at 66% of the dosage, while that of pineapple and banana was the highest with application of fertilizers in the full dosage. Later on Maheswarappa et al. (2013) evaluated the performance of coconut-based HDMSCS under organic and integrated nutrient management by using reduced doses of NPK fertilizers (2/3 or 1/3 of recommended dose), application of vermicompost (by recycling biomass), biofertilizers, green manuring (in basins) as well as fully organic manures. The mean nut yield, copra content and oil yield for 5 years did not differ among the treatments (ranging between 145 to 155 nuts palm^{-1} year^{-1}, 159.5 to 164.6 g nut^{-1} and 65.7 to 65.8%, respectively) indicating the beneficial effect of organic cultivation by recycling biomass, application of biofertilizers and green manuring.

Among the different HDMSCS models evaluated in a 27-year-old coconut garden of cv. Assam Tall spaced at 8.0 m × 8.0 m in India by Nath et al. (2008), the highest nut yield as well as per cent increase in nut yield was recorded with coconut + black pepper + banana + Assam lemon + pineapple + ginger. This was more profitable giving the highest net return of Rs.42,155 ha^{-1} with a B/C ratio of 1.67. Nath

Table 7.4 Output from crops under coconut-based high-density multispecies cropping system model in Kerala (1999–2005)

Fertilizer dosage (%)	Coconut (nuts palm^{-1} year^{-1})	Pineapple (kg fruit^{-1})	Clove (dry kg tree^{-1} year^{-1})	Banana (kg bunch^{-1})	Black pepper (kg dry) (bush^{-1} year^{-1})
100	145	0.89	1.44	5.76	0.87
66	147	0.70	1.55	5.43	1.66
33	147	0.57	1.25	4.70	0.90
25	137	0.43	1.12	4.36	1.06
20	129	0.48	1.00	3.91	0.42
Control	127	0.45	1.32	3.86	0.46

Full fertilizer dosage (N/P/K g plant^{-1}): coconut, 500:320:1200; pineapple, 8:4:8; clove, 300:250:750; banana, 200:200:400; black pepper, 50:50:150

and Deka (2010) also from Assam reported increase in yield of 28-year-old coconut garden spaced at 7.5 m × 7.5 m over the years after planting of various intercrops irrespective of different cropping systems, wherein the maximum increase of nut yield (68.62%) was recorded in coconut + black pepper + turmeric followed by coconut + black pepper + ginger (50%), while only 8.69% increase was observed in control (coconut + black pepper). The highest net return of Rs.1,46,549 ha^{-1} and B/C ratio 2.20, respectively, was recorded in coconut + black pepper + turmeric cropping system. Among the various multispecies cropping system models evaluated under 27-year-old ECT palm spaced at 7.5 m × 7.5 m in the east coast region of Tamil Nadu, India, coconut + black pepper + banana + elephant foot yam+ green leafy coriander) recorded the maximum net return of Rs. 57,577 with the B/C ratio of 2.16. The increase in cumulative nut yield in this model was 24.28% (Subramaniam et al. 2010).

7.6.7 Coconut-Based Mixed Farming

This involves integration of other subsidiary enterprises such as livestock, poultry, rabbitry, pisciculture and others along with the cultivation of fodder or pasture in the coconut garden. Coconut, due to its perennial nature, offers a unique opportunity for integration of animal husbandry enterprises such as rearing of cattle, goat or sheep to provide significant economic benefits to the farmer (Shelton 1991).

According to Darwis (1990), the coconut farming systems adopted by Indonesian smallholders can be classified into four types: farmyard, polyculture, monoculture and tidal swamp. In Java, about 79% of the coconut smallholdings fall within the polyculture pattern, where coconuts are grown with annuals, perennials or both types of intercrops and the remaining is coconut monoculture. In tidal swamp areas, coconuts are combined with fish, prawn, duck, crab or lowland rice production. In a polyculture system, involving perennial crops such as cloves, bananas, breadfruit trees (*Artocarpus altilis)* and sawo trees (*Manilkara kauki*), or pineapple and banana; the best profitable crops were pineapple and banana.

Much of the area under coconut plantations is under tall varieties which are often more than 30 years old, and therefore, light levels are high enough to support understorey vegetation such as pasture grasses. Sahasranaman and Pillai (1976) in India found that Guatemala grass (*Tripsacum laxum*), hybrid Napier (Pusa giant and NB 21) and guinea grass (*Panicum maximum*) are the ideal fodder crops which gave a yield of 50–60 mt of fresh fodder ha^{-1} $year^{-1}$ under coconut shade, while legumes such as Brazilian lucerne (*Stylosanthes gracilis*) and cowpea *(Vigna unguiculala)* yielded 30 tonnes ha^{-1} $year^{-1}$. At a feeding rate of 30–40 kg of fresh fodder in the ratio of 3:1 grasses and legumes $animal^{-1}$ day^{-1}, an area of 1 ha could support 4 milch cows.

Sahasranaman and Pillai (1976) reported 28% increase in nut yield in the root (wilt) disease-affected area by adopting mixed farming practice over a period of 5 years. Jacob Mathew and Mohamed Shaffee (1979) and Nelliat and Krishnaji (1976) indicated the incremental benefit of coconut + dairy over coconut alone. They also recorded increased coconut yield, satisfactory milk yield and employment potential for about 800–850 days as against 150 days for pure coconut.

Generation of additional employment from 150 man-days to 1000 man-days ha^{-1} by adoption of mixed farming was also reported (Sahasranaman and Pillai 1976; Sahasranaman et al.1976). Ferdinandez (1978) reviewed the studies done at the Coconut Research Institute, Sri Lanka, and reported that there was long-term beneficial effect on nut production by intercropping with certain pasture species, provided both crops are adequately fertilized and grown in favourable rainfall regions.

When grazing was introduced in coconut stands, a near doubling of coconut yield was reported by several researchers (Childs and Groom 1964; Ovasuru 1988; Moog and Faylon 1991). Moog and Faylon (1991) reported higher yield (80 to 100 nuts $palm^{-1}$ $year^{-1}$) when grazing was practised in gardens with improved pastures compared to that in gardens with natural pastures (30 to 50 nuts $palm^{-1}$ $year^{-1}$). Reynolds (1993) concluded that competition for moisture is likely to occur where annual rainfall is below 1750 mm, particularly if it is not evenly distributed.

A coconut-based mixed farming system involving 14 activities and integrating the crop and livestock systems was found to be the best in the linear programming model (Salam et al. 1991). The structural and functional diversity of the components of the system ensures a high level of resource use efficiency, meeting the multiple demands (food, fodder, fuel and timber) of the farmer. The model also recorded a B/C ratio of 1.64. Maheswarappa et al. (1998a) reported increase in nut yield under mixed farming by 39.6% and 33.5% for WCT and Laccadive Ordinary (LO) varieties of coconut, respectively. There was improvement in yield to the extent of 91.6 and 60.7% for WCT and LO, respectively, due to adoption of mixed farming (Maheswarappa et al. 2001). From an integrated nutrient management study, Subramanian et al. (2008) found that Bajra Napier hybrid (CO3) grown as intercrop in coconut garden under red sandy loam soil gave a fodder yield of 96 mt ha^{-1} $year^{-1}$ with the application of chemical fertilizers alone. In coastal sandy soil when Bajra Napier hybrid was grown as intercrop with soil moisture conservation measures, the fresh fodder yield obtained was 92 mt ha^{-1} $year^{-1}$ (Subramanian et al. 2007, 2009, 2012b).

From a comparison of the performance of 8 grass species, Smith and Whiteman (1983) from Australia recommended *Stenotaphrum secundatum* under deeper shade, with light transmission (LT) of 30–50%. In the Philippines, introduction of improved grasses or grass-legume pastures and cattle into coconut plantations resulted in total income ranging from US $ 608 to 809 compared to US $ 10 from coconuts alone (Deocareza and Diesta 1993). Stur et al. (1994) reviewed the available information on cattle rearing under coconuts, citing several examples in the Pacific Islands, and concluded that the level of production in such systems with adapted forages was comparable to that obtained in open conditions. The prevalence of the pasture-cattle-coconut systems in the different coconut-growing countries has been reviewed by Reynolds (1995). In the Philippines, CBFS integrates complimentary enterprises such as intercropping, livestock, processing of coconut products/by-products and marketing (Aguilar and Benard 1993).

The cropping systems practised in Sri Lanka include intercropping with seasonal and annual crops, mixed cropping with perennials, alley cropping with a combination of tree legumes and seasonal crops and mixed farming involving cattle and pasture (Liyanage and Dassanayake 1993). They also reported that coconut palms in the integrated system involving *Brachiaria milliformis/Pueraria phaseoloides* mixed pasture and *G. sepium* and *Leucaena leucocephala* fodder trees and crossbred cattle yielded 17% more nut and 11% more copra while maintaining the nutrient status of the palm above the critical level despite reduced application of fertilizer. Despite several factors which limit its widespread use by farmers, it was concluded that the coconut + cattle integrated system could contribute to the development of a sustainable and productive farming system in Sri Lanka (Liyanage and Dassanayake 1993). Iniguez and Sanchez (1991) estimated the percentage contribution of the cattle component in a coconut cattle system in Bali, Indonesia, to be 75.

The information available from the research on pasture species for the coconut plantations have been reviewed by Chen (1991), Reynolds (1993), Shelton et al. (1987), Stur and Shelton (1991) and Wong (1991). Various suitable pasture species have been identified, and their nutritional qualities have been ascertained (Norton et al. 1991). Intercropping coconut with nitrogen-fixing trees is a sustainable and productive land-use system. Such trees produce nutritious protein-rich fodder that supplements pasture feed, reducing grazing pressure. They also provide rich organic matter to the nutrient-poor soils of coconut plantations, besides additional farm products such as fuel wood and fodder. According to Dalla Rosa (1993a), *L. leucocephala* and *G. sepium* both perform well in the coconut understorey – yielding useful fodder, fuel wood and green manure.

Mantiquilla et al. (2000) evaluated various forages under coconut in Mindanao, the Philippines. *Brachiaria decumbens* applied with N fertilizer gave the highest DM yield of 24 t ha^{-1} year^{-1} in a grazing system, while *B. decumbens* or *Setaria sphacelata* grown with legumes yielded about 15 mt. In a cut-and-carry system, *Pennisetum purpureum* gave the highest yields, but the forage quality was higher with *Panicum maximum.* Nayar and Sahasranaman (1978) observed that mixed farming had little effect on the size of soil aggregates when observed after a period of 5 years. However, the system was found to improve soil physical properties such as water-holding capacity, porosity and hydraulic conductivity and reduce bulk density both in the coconut basins and grass-cultured plots (Maheswarappa et al. 1998a).

Progressive increase in coconut production was noticed by Anitha et al. (2010) from the initial yield of 24 nuts palm^{-1} to 42 nuts palm^{-1} in a 10-year-old coconut plantation, spaced at 8 m × 8 m square pattern (156 palms ha^{-1}) with the introduction of a unit of 10 meat goats ha^{-1} of coconut farm utilizing the natural feeds available in the farm. According to Premaratne and Somasiri (2011), mixed farming system involving ruminants provides regular supply of organic matter to the soil as daily excretion of faeces and urine (amounting to 9.5% and 3.5% of body weight of animals, respectively). Integration of coconut/livestock could also enhance the coconut production in the system due to the increase in fertility of soils from animal manure as well as removal of weeds by animals (Sahasranaman and Pillai 1976; Bopaiah and Shetty 1991a; Biddappa et al. 1993; Maheshwarappa et al. 1998a). Higher organic carbon, N, P and K status has been reported under grass-cultured plot. The addition of slurry from the biogas plant helps to add considerable organic matter into the system, thereby increasing the various microbial and biochemical properties of the soil. Among the grass species tried, guinea grass intercropped plots had higher available N, P and K compared to coconut + hybrid Napier Bajra intercropping. Soils under mixed farming showed relatively lower values of available Ca, Mg, Mn, Cu and Zn and marginal increase in available Fe status (Maheswarappa et al. 1998a). In the integrated system involving coconut, mixed pastures and crossbred cattle, Liyanage et al. (1993c) from Sri Lanka reported that recycling of animal excreta (73 kg fresh cattle manure and 30 l urine palm^{-1} year^{-1}) reduced the cost of fertilization of coconut by 69% and improved soil fertility by providing organic carbon, total nitrogen and available phosphorus. The integrated system was also found to be economically viable when compared with monoculture coconut. The beneficial microbial community increased significantly in the root region of coconut in the farming system compared to the populations in monocrop of coconut. Intercropping of fodder hybrid Napier with coconut palms resulted in the proliferation of total bacteria and nitrogen-fixing organisms in the coconut rhizosphere in root (wilt)-diseased and apparently healthy palms. Compared to the palms in the control plot, crop mixing enhanced phosphate-solubilizing bacteria in root region of root (wilt)-affected coconut palms harbouring significantly higher numbers (Potty and Jayasankar 1976; Potty et al. 1977). The hybrid Napier + *Stylosanthes gracilis* combination proved to be the best among the combined treatments because of low level of denitrifiers and comparatively high proliferation of nitrifiers (Sahasranaman et al. 1983).

Bopaiah and Shetty (1991b) found that bacterial counts were higher in the root zone of coconut and Napier grass in mixed farming than that in monocropping of coconut. Enhanced soil biological activity was also indicated by higher levels of microbial biomass and activities of soil enzymes (phosphatase and dehydrogenase) in the farming system. The impact of intercropping fodder grass and organic recycling on microbial proliferation was evident not only at 0–25 cm depth but also in 25–50 cm and 51–100 cm depths in the basin (Thomas et al. 2010b). Aparna and Arya Nath (2014) compared intercropping systems with fodder grass, banana, vegetables and tuber crops in red loam and laterite soils and found that coconut + fodder grass improved many of the soil physical and chemical attributes as the quantum of organic matter added or recycled to the soil was more compared to the others. The microbial activity was also more under organic system of cultivation which resulted in higher enzyme activities.

According to Dalla Rosa (1993b) and Reynolds (1995), some of the potential benefits of coconut-animal production systems are:

1. Improved nutritional security of farm family. Increased overall farm income (coconut and animals) and greater employment opportunities
2. Increased stability for coconut farms through crop diversification and reduced market and financial risks

3. Increased soil fertility and reduced fertilizer costs as cow dung and cow urine serve as organic manures for the cropping system
4. Improved growth and yields of coconut and effective understorey weed control
5. A better grazing environment for cattle provided by coconut and higher relative humidity and soil water availability for pasture

7.6.8 Coconut-Based Homestead Farming System

The homestead is an operational farm unit in which a number of crops (including tree crops) are grown mostly as coconut-based farming system involving livestock, poultry or fish, mainly for the purpose of meeting the farmer's basic needs. Homestead farms or home gardens can be found in almost all tropical and subtropical ecosystems where subsistence land-use systems predominate. Such systems can be found in Sri Lanka (Jacob and Alles 1987; Nimal 1989), Mexico (Rico Gray et al. 1990), India (Nair and Sreedharan 1986; Krishnakumar 2010; Subramanian et al. 2014), Bangladesh (Leuschner and Khalique 1987), Pacific Islands (Vergara and Nair 1985), Indonesia (Michon et al. 1986) and several other countries, each one with its own characteristics.

The small and marginal farmers of Kerala place high value on their homestead farms as a source of nutritional security, additional income and for risk minimization. These homestead farms also play a significant role in maintaining the quality of microenvironment within the farm. An array of agricultural, horticultural crops and other miscellaneous plants in the homestead farms indicate a high level of crop diversity. Homestead farms are known to be repositories of biodiversity. Coconut-based homestead farms often present crowding of all kinds of plants, and when interplanted with multipurpose trees, the light availability is considerably reduced. Homestead farming satisfies the requirements of sustainability by being productive, ecologically sound, stable, economically viable and socially acceptable (John 2014). Systematic homestead farming requires careful selection of crops, and the plot layouts should be well planned for maximum sunlight utilization and also to cover the entire ground area with the identified crops. Productivity from the coconut-based homestead farms can be further enhanced by integrating livestock into the unit, which helps recycling of nutrients. Salam et al. (1991) opined that the home garden system as seen in Kerala, though not scientifically laid out, is productive and ensures better efficiency of scarce resources of land, water, nutrients and solar energy. An economic analysis of the coconut-based cropping system using data collected from 172 holdings in Southern Kerala showed that labour, manure and land area have significant influence on productivity (Job et al. 1993). Krishnankutty et al. (2013) reported that the homestead farms in medium elevation lands in Palakkad district, Kerala, are predominantly with coconut-based cropping pattern, with coconuts, areca nuts and a few tubers as intercrops.

Nair and Sreedharan (1986) reported 66 cultivated crop species, while Jose and Shanmugharatnam (1994) documented more than 130 species in a single home garden, dominated by coconut as the main crop. They opined that the crops, though at first glance appear to be haphazardly planted, have definite spatial arrangement within the farm and these subsistence oriented systems were managed mostly by family labour. From a survey of 815 smallholding coconut farms in Kerala, Krishnakumar and Reddy (2007) reported that coconut-based cropping system was the most predominant homestead cropping system followed by majority of farmers (98.0%), and the size of homestead farms ranged from 0.04 ha to 2.40 ha with the average being 0.54 ha. As the size of homestead farms increased, there was an increase in the investment made and the profit obtained on account of cultivation of coconut and other intercrops coupled with other enterprises. Later on, appropriate interventions in crop production technology and management practices in a farmer participatory approach were identified, and restructuring of homestead farms has led to increase in cropping intensity ranging from 56% to 86% in Kerala, India (Krishnakumar et al. 2007). An economic analysis indicated that the maximum income could be realized by those farmers having land holdings of more than 0.4 ha size (Krishnakumar 2010).

John and Nair (1998) developed an integrated model for small coconut-based homesteads (0.2 ha) by linear programming. One model consisted of 43 enterprises with a cropping intensity of 162%. Such a model could provide a net profit of Rs.37,426 on investing Rs.25,000 indicating a B/C ratio of 2.5. The amount of sunlight transmitted in coconut stand was 36% (John and Nair 1999), whereas when interplanted with multipurpose trees, the light availability was reduced to less than 1 %. Therefore, meticulous selection of understorey crops and their varieties, timely planting, following the temporal sharing concept and selective pruning of overstorey canopy for shade regulation could mitigate the problem of low light availability and improve overall productivity of the system. A net income of Rs.5,50,214 ha^{-1} $year^{-1}$ could be realized from 1 hectare of coconut-based homestead farming model comprising of coconut with black pepper trailing on its trunk, banana, cows, fodder grass, poultry and aquaculture at ICAR-CPCRI (Maheswarappa et al. 2001; Subramanian et al. 2014).

Studies by Pandey et al. (2014) from South Andaman Islands of India indicated that the coconut palms extended their roots quite close to the companion crops, but companion crops extended their roots only up to a certain distance within the radius of their canopies. Thus, the main crop and its intercrops separated their niches horizontally. While there was facilitative mechanism by the main crop to its associative crops above the ground, there existed an exploitative mechanism below the ground.

The floral diversity of homestead farms of various agroclimatic zones of 14 districts of Kerala, covering 2500 farmers, was studied (Krishnakumar et al. 2010). Coconut was the base crop in most of the homestead farms surveyed, with the interspace of which a wide variety of crops ranging from annuals to perennials were cultivated so as to generate cash income after meeting the subsistence needs. John et al. (2010) found coconut+ black pepper+ nutmeg to be the most sustainable system in terms of economics and environmental consideration followed by coconut+ black pepper+ vanilla. Kalavathi et al. (2010a, b) reported significant improvement in food and nutritional security as well as farm family income of 150 small and marginal coconut homesteads of three community-based organizations (CBOs) of Kerala, through integrating interventions like intercropping, livestock rearing and product diversification. Diversification of crops and coconut-based enterprises implemented through CBOs emerged as the most effective strategy for improving the quality of life of the marginal coconut farmers – both in terms of income and food and nutritional security.

7.7 Harnessing Beneficial Microbial Resources

The beneficial effect of incorporation of legume creepers was reflected in the counts of total microflora, asymbiotic nitrogen fixers, P solubilizers, and enzyme activities. Soil spore counts and mycorrhizal infection of coconut roots were also increased in green manure applied plots (Thomas 1987). Association of legumes with efficient strains of *Rhizobium* spp. helps the nitrogen-rich green matter to be easily decomposed and the bound nutrients to be released. In order to enhance symbiotic effectiveness of rhizobia in green manure legumes, the introduced strains of rhizobia can be protected against acidic soil conditions by pelleting with alkaline substances such as lime and rock phosphate (Thomas and Ghai 1991).

Field experiment to evaluate the effect of green manure legumes on root (wilt) disease index and coconut yield indicated that basin cultivation and incorporation of *M. invisa* and *P. phaseoloides* increased coconut yield by 21.6 and 14.7%, respectively (Thomas and George 1990). Thomas et al. (2001a) reported the possibility of substituting 25–50% N fertilizer by raising either *C. mucunoides* or *M. invisa* in coconut basin.

HDMSCS promotes the proliferation of microbial diversity and biological activities to a great extent (Bavappa et al. 1986). In the HDMSCS with black pepper, banana, clove and pineapple as component crops, the root region of coconut recorded a sixfold increase in the population of bacteria and two- to threefold increase in population of fungi in the cropping system at different depths in coconut basins, compared to the monocrop of coconut (Bopaiah and Shetty 1991a). Bacteria formed the most important component followed by actinomycetes and fungi in the root region of coconut. The resource heterogeneity resulting from above-ground crop diversity might have led to greater diversity of decomposers and detrivores. The positive impact of cropping system was reflected on the soil microbial biomass carbon, soil microbial nitrogen and soil enzyme activities. Medium levels of fertilizer inputs along with organic recycling favoured higher activities of soil enzymes in the cropping system. The highest values of microbial biomass were recorded at 1/3 recommended levels of NPK (Kavitha 2009). The ratio of microbial biomass to total carbon was high in rhizosphere of coconut under the cropping system indicating higher contribution of microbial biomass to total carbon. This shows the occurrence of large portion of inactive biomass at higher doses of mineral fertilizer inputs (Thomas et al. 2016). Rohini Iyer (1983) reported that black pepper and coffee grown with 1/3 doses of fertilizer application supported the maximum mycorrhizal activity, whereas for banana, clove, and pineapple, a 2/3 dose was found to exhibit maximum activity.

Arbuscular mycorrhizal fungi belonging to the five genera, *Glomus*, *Gigaspora*, *Scutellospora*, *Serelerocystis* and *Acaulospora*, formed symbiotic association with roots of coconut seedlings (Thomas et al. 1991). A study on diversity of AM fungi associated with coconut intercropping systems of Kerala, India, revealed that mycorrhizal parameters like spore density, root colonization, species richness and relative occurrence of species varied significantly among the cropping systems (Ambili et al. 2012). The diversity of fungal species was reported to be maximum in the HDMSCS of ICAR-CPCRI, Kasaragod, India, with coconut as the main crop and banana, black pepper, pineapple and clove as component crops. From the coconut palm cultivated in crop mixed system under rainfed condition in a highly productive zone in Kerala, India, 40 AM species belonging to 10 genera were recorded indicating high level of AM richness in coconut rhizosphere (Rajeshkumar et al. 2015). A study on second generation high-density multispecies cropping system in Assam revealed the highest level of stimulation of microbial community in coconut + black pepper + turmeric cropping system followed by that in coconut + black pepper + ginger cropping system (Nath and Deka 2010), whereas in the east coast region of Tamil Nadu, the microbial proliferation was the highest in the model having coconut + black pepper + banana + elephant foot yam + greens (Subramaniam et al. 2010).

Plants exert influence on soil microbial communities through root exudates, which directly or indirectly influence plant growth (Bopaiah et al. 1987). The root exudates of coconut from mixed farming and multistoried cropping systems had significantly higher total sugar, amino acids and phenol content when compared to monocrop of coconut. Amino acids constituted an important component of organic fraction in root exudates of coconut and component crops in the cropping system (Kavitha 2009). The total amino acid content varied in relation to the fertilizer treatments in the root exudates of coconut (282.90 μ mol. g^{-1} root) and component crops, viz. pineapple, banana and clove (253.35–303.00 μ mol. g^{-1} root). The amino acids recovered from the root exudates of coconut and component crops showed various proportions of acidic and neutral amino acids.

Investigations on various cropping systems over several decades have revealed the profound influence of the cropping systems in supporting higher population of plant beneficial microbial community comprising of bacteria, fungi and actinomycetes in the rhizosphere and root region of the main crop coconut, irrespective of the crops which formed the components (Nair and Subba Rao 1977a; Potty et al.1977; Antony 1983; Rohini Iyer 1983; Thomas 1987; Bopaiah and Shetty 1991a, b; Kavitha 2009; Nath and Deka 2010).

Mixed cropping of cacao in coconut plantations improved the microbial activity in the rhizosphere of coconut to a higher level which was also attributed to an increase in organic matter content of soil due to periodic shedding of cacao (Nair and Subba Rao 1977b). Intercropping of fodder grass hybrid Bajra Napier with coconut palms resulted in the proliferation of total bacteria and N-fixing organisms in the rhizosphere of apparently healthy and root (wilt)-diseased coconut palms compared to the palms in the monocropped plot (Potty et al. 1977). Antony (1983) reported increase in soil microflora in the rhizosphere of root (wilt)-diseased coconut palms as a result of intercropping with tuber and rhizome crops.

7.7.1 Microbial Resources with Function-Specific Traits

Function-specific microorganisms which are found to be of great relevance to the growth and productivity of coconut and intercrops belong to 5 groups, viz. N-fixing bacteria in the rhizosphere, N-fixing *Rhizobium* living in symbiosis with legumes, phosphate-solubilizing bacteria, phosphate-solubilizing fungi and arbuscular mycorrhizal fungi (AMF). The constant association of beneficial microbes with the roots helps the palm in several ways contributing to the establishment, survival and growth, particularly in nutrient-poor soils and under drought conditions. Studies on mycorrhizal colonization showed that drought-tolerant genotypes were superior to the susceptible ones in harbouring a higher level of mycorrhizae colonization in roots, indicating the active role of host-fungus association under the conditions of low water availability (Thomas et al. 1993). Summer irrigation had a positive influence on AM symbiosis in coconut (Harikumar and Thomas 1991). The root region of coconut palm is inhabited by a number of free-living and associative N-fixing bacteria which possess different levels of N-fixation activity. *Beijerinckia indica* is the predominant asymbiotic N_2 fixer, capable of fixing N under acidic soil conditions in coconut soils, and is also endowed with the properties of production of polysaccharides which help in soil aggregation (Merilyn and Thomas 1992).

A study on 26 crops including plantation crops and intercrops in different cropping systems revealed the occurrence of *Azospirillum* in different levels in coconut-based farming systems (Ghai and Thomas 1989). The coconut harboured endophytic association of unique diazotrophs with N-fixation and plant growth promotion properties (Thomas et al. 2001a; Thomas and Prabhu 2003). Fungal isolates from coconut soils, particularly those of *Aspergillus* and *Penicillium* species, possess high level of phosphate-solubilizing ability solubilizing up to 72% of insoluble phosphorus supplied (Thomas et al. 1985). Inoculation of soils with efficient phosphate-solubilizing bacteria after addition of farmyard manure and rock phosphate results in the release of more available P from insoluble P sources (Thomas and Shantaram 1986). Coconut rhizosphere soils have also been found to harbour potassium-solubilizing bacteria belonging to *Acinetobacter*, *Alcaligenes* and *Micrococcus* species (Alka Gupta et al. 2016).

From an extensive study on plant growth-promoting rhizobacteria (PGPR) associated with coconut involving rhizosphere and root samples from 5 states of India, 512 PGPR isolates were collected which were found to possess various plant growth promoting and biocontrol traits (Priya George et al. 2012a, c). They observed that pseudomonas isolates from coconut rhizosphere showed antagonism towards *G. applanatum* and *T. paradoxa* and significantly inhibited both pathogens.

The dose of fertilizer applied has a direct bearing on the mycorrhizal activity, and this may vary with host-fungus combinations. A good number of AM fungi can withstand only low concentrations of soil nutrients. AM infection is negatively related to the available soil P (Harikumar and Thomas 1991). Root (wilt) disease had an adverse effect on AM symbiosis in coconut which was highly pronounced in disease advanced palms (Thomas 1988). Thomas and Ghai (1987) reported genotype-dependent variation in AM colonization in coconut, and the tall cultivars had higher level of colonization than dwarfs and hybrids.

7.7.2 Biofertilizers as Inputs in Coconut Production

Formulations containing living cells of beneficial microorganisms multiplied in a suitable carrier can form low-cost eco-friendly inputs for organic coconut production. The group of microorganisms responsible for biological N-fixation, P-mobilization, uptake of immobile elements, biological control and production of plant growth-promoting substances have been found to be closely associated with the coconut palm (Thomas and Prabhu 2003; Priya George et al. 2012a, b, c; Rajeshkumar et al. 2015). Isolations and multilevel screening of microbes from coconut ecosystem resulted in selection of efficient strains and development of microbial formulations for application in crop production. These bioinoculants enhanced root biomass and branching of secondary roots of the coconut seedlings. Inoculation of PGPR, viz., *Brevibacillus brevis* and *Bacillus coagulants*, resulted in production of coconut seedlings with high seedling quality index (Alka Gupta et al. 2006). Significant improvement in seedling growth parameters such as girth and root production was recorded when *Azospirillum brasilense* was applied to coconut seedlings raised in poly bags containing the potting media of coir pith-soil-sand mixture (Srinivasa Reddy et al. 2001).

Research efforts on harnessing the rich microbial resources associated with coconut palm resulted in the development and release of talc-based bio-formulations of plant growth-promoting rhizobacteria (PGPR), viz. 'CPCRI Kera Probio' based on *Pseudomonas* sp. for application to coconut. KerAM, a soil-based arbuscular mycorrhizal (AM) formulation, containing *Claroideoglomus etunicatum*, as the dominant AM species isolated from coconut agroecosystem with high potential to increase the growth parameters of coconut seedlings, is another resource made available as bioinoculants in coconut (Thomas et al. 2016). In Sri Lanka, Ilangamudali and Senarathne (2016) found mixing arbuscular mycorrhizal fungus-based biofertilizer at 50 g with potting medium in each poly bag at the time of planting seed nuts to be beneficial to produce quality seedlings with well-developed roots, which gave good establishment in the field.

Field experiments conducted at ICAR-CPCRI, Kasaragod, India, revealed that PGPR strains *Bacillus megaterium* TSB16 isolated from coconut and *Pseudomonas putida* KDSF23 from cacao can be used as a bioinoculant for vegetable production in organic agricultural systems indicating cross-compatible nature of PGPR. They can also serve as a single bioinoculant for coconut and vegetables in coconut-based cropping system (Khadeejath Rajeela et al. 2016).

7.8 Organic Farming as a Viable Strategy in Coconut

Organic farming is a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles and soil biological activity, as per FAO/WHO Codex Alimentarius Commission. In organic production systems, agronomic, biological and mechanical methods of management practices are adopted avoiding the use of synthetic materials. Organic farming system is defined as an integrated farming system that strives for sustainability, the enhancement of soil fertility and biological soil fertility while, with rare exceptions, prohibiting synthetic fertilizers, synthetic pesticides, antibiotics, genetically modified organisms and growth hormones (Paull 2010).

Coconut is one of the most amenable crops for organic farming, and a number of agro-techniques are available for organic cultivation (Prabhu et al. 2000; Thomas et al. 2001b, 2010a, b, 2012a). Recycling of waste biomass available in coconut plantations, cultivation of N-fixing leguminous green manure crops, biofertilizers and biopesticides are vital inputs in organic cultivation of coconut. Bio-resource-based strategy to strengthen biological foundations of soil fertility is of vital importance to achieve sustainable productivity (Thomas et al. 2012b). The diversified farming system, for which coconut is very amenable, will also enable addition of large quantities of organic matter and their effective recycling within the system helping to increase organic content of soil, improve microbial activity and make the entire production system more productive even with little or no external inputs.

7.8.1 Vermicomposting of Coconut Leaf Biomass

The technology for bioconversion of lignin-rich crop residue biomass available abundantly in coconut gardens to enrich organic resource, using local earthworm, gives a new dimension to biological soil fertility management and crop nutrition in coconut. The availability of biomass from well-managed coconut garden with 175 palms ha^{-1} is estimated as 14 tonnes ha^{-1} $year^{-1}$ in the form of leaves, spathe, bunch stalk and husk. Though major portion of husk is used for extraction of coir fibre, coir dust (the by-product of coir processing factories) can be used as a bio-resource after biodegradation. The organic biomass can either be converted into compost by using earthworms or microbial cultures. Coconut palm residues, being very hard, are decomposed rather slowly, and hence vermicomposting has great relevance. Lignocellulosic residues from coconut plantations can be converted into brown, granular vermicastings using earthworms. At ICAR-CPCRI, a local earthworm (*Eudrilus* sp.) closely related to the African night crawler and very effective in vermicomposting of coconut palm residues has been isolated, and the methodology for vermicomposting has been standardized (Prabhu et al. 1998).

The recovery of compost is as high as 70%. The vermicompost, thus, produced has a nutrient content of 1.8% N, 0.21% P and 0.16% K with a C/N ratio of 9.9. From a 1 hectare coconut garden, it is possible to produce around 4 tonnes of vermicompost from coconut leaves alone. The vermicompost produced from coconut leaves using *Eudrilus* sp. at ICAR-CPCRI is available in the trade name ‘Kalpa Organic Gold’. In coconut plantations with irrigation facilities, in situ vermicomposting can be done in basins or in trenches dug in interspaces of four coconut palms or by the heap method in plantations. This will enable disposal of coconut residues in a less expensive and eco-friendly manner with the benefit of producing high quality manure in coconut plantation.

The vermicompost increases soil fertility through addition of plant nutrients, growth hormones, increased level of soil enzymes and important microorganisms as they are rich in microbial diversity, population and activity. The agro-residues from component crops in the cropping system like banana, pineapple and others recycled through vermicomposting process produce quality organic manure (Thomas et al. 2012b). Application of entomo-pathogenic fungus, *Metarhizium anisopliae*, along with coconut leaves in vermicomposting tanks, was effective for the control of *Oryctes rhinoceros*, which multiplies in coconut leaf substrate during vermicompost production (Murali Gopal et al. 2006). Nine out of 15 microbial communities, particularly the plant beneficial ones, were enriched in the vermicompost produced from coconut leaves + cow dung mixture compared to 5 communities in vermicompost produced from cow dung alone. The coconut leaf vermicompost contained significantly high population of fungi, free-living nitrogen fixers, phosphate solubilizers, fluorescent pseudomonas and silicate solubilizers (Murali Gopal et al. 2009).

Vermiwash is a liquid organic fertilizer generated as a spin-off technology from vermicompost production. Coconut leaf vermiwash produced during vermicomposting of coconut leaves had the properties to increase crop production capacities of soil by enhancing the organic carbon content in the soil and increasing the populations of the soil microorganisms, particularly plant beneficial ones and their activities which facilitated increased uptake of the nutrients by the plants. Application of coconut leaf vermiwash (CLV) was observed to boost the biomass yield of crops such as cowpea, maize and bhendi (Murali Gopal et al. 2010, 2012).

7.8.2 Bioconversion of Coir Pith to Valuable Resources

Coir pith, with high C/N ratio and lignin and polyphenol content, is resistant to natural degradation. It can be made more amenable for earthworm/microbial activity and subsequent decomposition by various chemical and decomposition methods. The *Eudrilus* sp. of earthworm was found to be ideal for vermicomposting of coir pith when mixed with coconut leaves (Thomas et al. 2001b), producing granular vermicompost in 2 months with 1.2% N and a C/N ratio of 16.7:1. The composted biomass was found to be of superior quality with respect to content of major and micro nutrients and plant beneficial microorganisms particularly the bacteria involved in nutrient transformation and growth promotion.

Co-composting of coir pith can be done using poultry manure, lime and rock phosphate at 10 kg, 0.5 kg and 0.5 kg, respectively, for every 100 kg of coir pith. This brings about bioconversion of coir pith to a final product in 45 days, which possesses physicochemical characteristics required for quality organic manure with low C/N ratio (21.42), which is considered as a maturity index of composting process (Thomas et al. 2013). The composted coir pith can be used as manure in coconut plantations and can increase the capability of soils to store moisture and nutrients. The coir pith compost, thus, produced has been released with the trade name 'Kalpa Soil Care' by ICAR-CPCRI.

Ghosh et al. (2007b) composted coir pith fortified with edible oyster mushroom and urea in a multilayer heap fashion using perforated PVC pipes. The composted pith was an excellent organic manure, with a reduced C/N ratio of 20:1, pH of about 6.5 and electrical conductivity of 0.23 dS cm^{-1}. Tripetchkul et al. (2012) attempted multilayered heap composting of coir pith and obtained compost within 21 days. Forced aeration during composting of coir pith is not necessary if coir pith is fortified with cow manure, rice bran and coconut water and operated under low C/N ratio; however, maturity was reached only at 35 days of post-composting.

Use of microbial starter cultures having lignin degradation capacity enhances the decomposition of coir pith (Nagarajan et al. 1985). The efficacy of various biocontrol agents such as *Trichoderma* and *Chaetomium* with cellulolytic activities was tested for degrading coir pith (Ramamoorthy et al. 1999). The work done at ICAR-CPCRI, Kasaragod, resulted in the isolation of an efficient ligninolytic basidiomycete fungus, *Marasmiellus troyanus.* Studies on naturally decomposing coconut biomass resulted in the isolation of efficient ligninolytic and cellulolytic fungi such as *Lepista* sp., *Lentinus squarrosulus* and *Schizophyllum commune* with degradation potential (Thomas et al. 2001a). Lignocellulosic biomass from coconut palm including coconut leaf stalk and bunch waste could be used as substrate for cultivation of oyster mushroom with a biological conversion efficiency of 57–70%, and the spent substrate available after the cultivation can be utilized as quality organic manure for crop production (Thomas et al. 1998a). Mixing of coir pith and leaflets with leaf stalk, bunch waste and leaflets resulted in higher yield of mushrooms (Thomas et al. 1998b). Crop duration of *Pleurotus sajor-caju* (oyster mushroom) was more in lignocellulosic biomass of coconut, particularly when leaf stalk was the substrate.

7.8.3 Direct Utilization of Organic Matter

Coconut husk, coir pith and leaves are ideal materials for use as mulch in coconut basins due to their lignocellulosic nature which offer resistance to microbial decomposition. Mulching is an important cultural practice in coconut gardens not only to conserve moisture and soil but also to suppress the weed growth and supply nutrients and organic matter. One hundred husks will provide 1 kg of potash apart from 270 g N and 150 g P_2O_5 (Jothimani 1994). Effect of husk buried will be observed from third year onwards, and the beneficial effect lasts for 5–6 years. The biomass available from inter/mixed crops can be used for mulching and as a source of nutrients in coconut plantation. Cacao, as a component of multiple cropping system, adds substantial quantity of organic matter to the soil. When grown under single and double hedge system in adult coconut plantation, cacao litter fall was to the tune of 818 and 1785 kg ha^{-1} year^{-1}, respectively, on oven-dry basis (Varghese et al. 1978a, b). With a nutrient content of 2.84% N, 0.26% P and 1.73% K (Eernstman 1968), the cacao leaf litter in the double hedge system could contribute 50 kg N, 11 kg P_2O_5 and 35 kg K_2O every year to the soil in the coconut-cacao mixed cropping system. Effective recycling of organic materials (farmyard manure, poultry manure, cow urine, cowshed washing, etc.) from 1.2 ha coconut garden adopting coconut mixed farming could supply 125 kg N, 78 kg P_20_5 and 115 K_20 year^{-1} (Maheswarappa et al. 1998a).

7.8.4 Field Validation of Organic Farming Technologies

From a 6-year study on coconut-based integrated farming system (CBIFS) maintained with only organic inputs, a mean yield of 108 nuts palm^{-1} year^{-1} from coconut could be obtained in addition to a fodder yield of 106 t ha^{-1} year^{-1} (Table 7.5). The soil nutrient status in terms of organic carbon and available N and P was substantially improved under organic treatments. However, the K content was low due to the higher uptake of K by coconut and fodder crop. The integrated system was highly remunerative with an average net return of Rs. 2,85,512 ha^{-1} achieving economic and environmental advantages. Organic farming with integrated package of biological management practices, involving animal husbandry enterprises, avoiding

Table 7.5 Effect of nutrient management on yield of coconut and fodder grass in CBIFS

Treatments	Mean coconut productivity (nuts palm^{-1})	Mean hybrid Bajra Napier (CO3) yield (fresh fodder tonnes ha^{-1})	Crude protein content of fodder (%)
Coconut monocrop + recommended fertilizers	97		
CBIFS: 50% inorganic fertilizers + 50% through organics	119	117	12.19
CBIFS: 100% through organics	108	106	12.69
CBIFS: 100 % through inorganics	106	96	11.94

all chemical inputs, enables to achieve sustainable productivity from coconut plantations. The integrated farming system under higher organic inputs recorded very high level of microbial biomass content and enzyme activities of phosphatase and dehydrogenase in the root region soils, indicating the stimulation of biological and microbial activities (Thomas 2010).

Organic farming has been found to be feasible in coconut with integrated treatments utilizing organic and bio-inputs including recycling of waste biomass by vermicomposting, in situ cultivation and incorporation of leguminous cover crops and biofertilizers of *Azospirillum* and *Bacillus* at 100 g each annually and other cultural practices including irrigation through the drip system in summer months.

A long-term study (2003–2014) conducted at ICAR-CPCRI, Kasaragod, India (Thomas et al. 2010b; Subramanian et al. 2016) has clearly indicated the possibility of organic farming in coconut under coastal ecosystem. The increase in yield for WCT variety of coconut was 65% (from the mean yield of 55 nuts palm^{-1} year^{-1} to the mean yield of 96 nuts palm^{-1} year^{-1}), while that of Chandrasankara (COD x WCT) was 55% (from the mean yield of 68 nuts palm^{-1} year^{-1} to 108 nuts palm^{-1} year^{-1}), respectively, during the initial 3 years of conversion period and during the 8 years of post-conversion period (Table 7.6). The practice of vermicomposting the recyclable biomass in trenches made in the interspaces, application of biofertilizers (Phosphobacteria and *Azospirillum* at 100 g palm^{-1}), raising cover crop in basins and its incorporation were found to be the best for improvement in soil nutrient status and enhancement of soil microbial population, as well as nut yield and copra content.

From an analysis of organic farming practices followed by 150 coconut farmers from Tamil Nadu, Kerala and Karnataka, India, Jaganathan et al. (2013) reported that growing intercrops, use of green manure crops and mulching were the main agronomic practices adopted. The major organic inputs produced or prepared at the farm were crop residues, farmyard manure, cow dung slurry and vermicompost. The mean yield and productivity of coconut was found to be 93 nuts palm^{-1} year^{-1} and

Table 7.6 Effect of organic and biological sources of nutrients on yield of WCT and COD x WCT coconut palms (nuts palm^{-1} year^{-1})

Treatments	Yield during the conversion period (2003–2006)		Mean yield (2007–2014)	
	WCT	COD x WCT	WCT	COD x WCT
Vermicomposting (in basin) + biofertilizers + cover cropping in interspace	67	74	88	106
Vermicomposting (in trenches) + biofertilizers + basin management with cover crops	64	77	96	108
Vermicomposting (in basin) + biofertilizers + intercropping vegetables	66	72	88	98
Vermicomposting (in trenches) + biofertilizers + intercropping vanilla and black pepper	68	77	91	107
Control	54	64	55	68

13,140 nuts ha^{-1}, respectively. Experimental results from long-term trials and the experience in farmers' gardens revealed that organic farming can become a viable strategy for sustainable coconut production, providing greater advantages in terms of ecological and economic benefits, with locally available resources and adoption of integrated farming involving animal husbandry enterprises.

From the experiments conducted over the years, the following practices are suggested for organic farming in coconut:

1. Use of seed nuts from organically grown plantations or from plantations where chemicals are not used.
2. Raising of seedlings without chemical inputs with bio-priming of PGPR, arbuscular mycorrhizae, *Azospirillum* and phosphobacteria.
3. Adopting a suitable spacing of coconut to facilitate inter/mixed cropping.
4. Recycling of biodegradable biomass from coconut, intercrops and animal origin by on-farm vermiculture.
5. Planting of leguminous cover crops and green manure crops in basins or interspaces.
6. Application of biofertilizers of nitrogen-fixing bacteria, P-mobilizing bacteria and plant growth-promoting rhizobacteria (PGPR).
7. Promoting biodiversity by inter/mixed cropping or high-density multispecies cropping by growing annuals, biennials and perennial crops.
8. Establishing mixed farming system with dairy unit including milch cows and raising fodder crops in interspaces. Subsidiary enterprises such as poultry, rabbitry, pisciculture, bee keeping and sericulture could be included.
9. Mulching with organic wastes from coconut to improve moisture holding capacity.
10. Irrigation to avoid moisture stress during summer months, preferably adopting drip irrigation.
11. Use of biopesticides such as microorganisms, parasites, predators and natural plant-based pesticides to manage the pests and diseases.

7.9 Future Thrust

The future strategies in coconut production should focus on higher level of productivity with cost-effective technologies based on natural resource management aimed at achieving competitiveness in coconut cultivation across all the producing countries through the following measures:

Achieving higher productivity in organic farming through integrated application of the technologies, approaches for replenishing higher export of K through appropriate means since there are reports of K becoming deficient under prolonged organic cultivation, explicit elucidation of information on the economic viability and long-term effect of adopting organic farming on soil properties and environment, research on impact of climate change on coconut cultivation, developing climate-resilient technologies which permit adaptation of the crop to climatic changes and building crop soil resilience, designing soil and crop management strategies based on conservation and effective utilization of natural resources to enhance sequestration of organic carbon, to improve the quality of soil and to prevent the loss of carbon as carbon dioxide with a view to mitigating the adverse effect of global warming, identification of constraints in coconut cultivation and standardization of precision farming, using Global Positioning System and Geographical Information System, development of site-specific management practices for optimum utilization of resources to achieve higher productivity simultaneously reducing the environmental hazards of overapplication of fertilizers and chemicals, developing cropping/production systems with higher nutrient and water use efficiency incorporating the beneficial properties of crop diversity, conservation agriculture and the rhizosphere ecology playing a crucial role in soil nutrient dynamics, plant nutrient uptake and soil health, utilization of the enormous potential existing in use of bio-resources, recycling of waste biomass, tapping nitrogen-fixing potential of legumes, utilizing plant-microbe synergy and biofertilizers, better understanding the microbiome of coconut roots and identifying novel molecules produced from rhizosphere microorganisms, and validate them for nutrient use efficiency and soil health management to achieve sustainable production in an eco-friendly manner.

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